US Army Corps
of Engineers®
Galveston District

Gulf Intracoastal Waterway
Aransas National Wildlife Refuge

Dredged Material Management Plan

DRAFT

SOUTHWESTERN DIVISION

SEPTEMBER 2000

GALVESTON DISTRICT

Table of Contents

List of Appendices

Gulf Intracoastal Waterway
Aransas National Wildlife Refuge
Dredged Material Management Plan

1.0 Purpose. The purpose of the 50 year Dredge Material Management Plan (DMMP) is to assist the Corps and sponsor to plan and program funding of channel maintenance for the Gulf Intracoastal Waterway (GIWW) near the Aransas National Wildlife Refuge (ANWR). The plan will also document the investigations, analyses, design, and monitoring to support the DMMP.

2.0 General. This plan describes planning information relevant to wetland creation, design and construction consideratiosn for Beneficial Use Sites (BUS) and contains the results of geotechnical investigations and analyses performed to support the project DMMP design. Unless otherwise stated the following paragraphs describe the future project operation and maintenance specifically for upland Placement Area (PA) use, Beneficial Use Sites (BUS), and management as it relates to design of the DMMP. Detailed geotechnical investigations and analyses for the Upland Placement Areas and Beneficial Uses Sites from Station 696+000 to Station 860+000 will be required prior to development of plans and specifications for these project features.

3.0 50-Year Placement Plan. A 50-year placement plan has been developed based upon existing archived data for this area. Compilation of the last 20 years of historical shoaling rates and previous dredging maintenance quantities allows us to project future placement cycles and quantities with high degree of accuracy provided area conditions remain constant. Looking at the history of dredging cycles between stations 696+000 and stations 860+000 indicate this reach of the GIWW be subdivided into five reaches based upon time intervals as shown on Schedules of Estimated Dredging Cycles and Material Quantities, Tables 1 through Table 5. Additionally, site elevations per cycle can be viewed graphically as shown on figures 1 through 9, for the upland placement sites and the first four BUS A, B, D and K.

4.0 Field Investigations. The following is a description of the field investigations performed for the Upland Placement Areas, Beneficial Use Sites and Dredge Maintenance Material.

4.1 Upland Placement Areas. Twenty borings, designated as borings 94-157 through boring 94-176, were drilled along the perimeter levees of the six existing Upland Placement Areas. Existing placement areas are designated as PA 127, PA 129, PA, 130a, PA 130b, and PA 131 as shown on Exhibits C-1-1 through C-1-4. There is one proposed upland site located near Station 692+000 and detailed investigations are pending purchase of the land. All borings were continuously sampled with 3-inch diameter Shelby tubes where clays were encountered. Where cohesionless materials were encountered, samples were taken with a split spoon during performance of Standard Penetration Testing. All samples were visually classified in the field and the consistency of the cohesive undisturbed samples was measured with a pocket penetrometer. Representative samples were tested in the laboratory for shear strength, classification, moisture content, unit weight, and Atterberg Limits. The Upland Placement Area boring layout and logs of borings are shown on Exhibit C-1 drawings 1 through 4 and Exhibits C-2-1 & C-2-3 of Appendix C.

TABLE 1

DREDGING AND PLACEMENT SUMMARY

Reach	Location	Station	to	Station	Placement Area	Dredge Interval (yrs.)	CY/Cycle *
1	Matagorda Bay To San Antonio Bay (Welder Flat)	696+000 716+000		716+000 724+000	New Upland Site PA122/Marsh	12	399,000
2	Turnstake To Liveoak Point (San Antonio Bay)	724+000 730+000 742+000 750+000 759+000 769+000		730+000 742+000 750+000 759+000 769+000 775+000	Site A/PA 122 PA122 PA123 PA124 PA125 Marsh/PA127	3	192,200 468,000 321,700 329,300 383,400 227,000
3	San Antonio Bay To Aransas Bay (ANWR)	775+000 785+000		785+000 792+000	Marsh/PA 127 Marsh/PA 129	4.5	291,000 203,000
4	San Antonio Bay To Aransas Bay (ANWR)	792+000 805+000 815+000		805+000 815+000 830+000	Marsh/PA 129 Marsh/PA 130A Marsh/PA 130B	11	256,000 82,600 159,900
5	Across Aransas Bay (Aransas Bay)	830+000 839+000 843+000 853+000		839+000 843+000 853+000 860+000	Marsh/PA 131 PA 132 PA 133 PA 134	3.5	340,000 180,000 261,200 196,600

Table 2

Placement Plan for Maintenance Material

Reaches 1 and 2 – Station 696+000 to Station 775+000

Cycle	Year	Reach 1 Sta.696+000 to Sta.716+000	Reach 1 Sta.716+000 to Sta. 724+000	Reach 2 Sta. 724+000 to Sta. 730+000	Reach 2 Sta. 730+000 to Sta. 742+000	Reach 2 Sta. 742+000 to Sta. 750+500	Reach 2 Sta. 750+000 to Sta. 759+500	Reach 2 Sta. 759+500 to Sta. 769+500	Reach 2 Sta. 769+000 To Sta. 775+000
CY/Cycle		399,000	167,100	192,200	468,000	321,700	329,300	383,400	227,000
1	1.0			Site A Marsh 20 acres	PA 122	PA 123	DA 124	DA 125	Site D Marsh 29 acres
2	3.0			Site A Marsh 20 acres	PA 122	PA 123	DA 124	DA 125	DA 127
3	6.0			PA 122	PA 122	PA 123	DA 124	DA 125	Site B Marsh 29 acres
4	9.0	New Upland Site	Site A Marsh 18.0 acres	Site A Marsh 20 acres	PA 122	PA 123	DA 124	DA 125	DA 127
5	12.0			Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	Site B Marsh 29 acres
6	12.0			PA 122	PA 122	DA 123	DA 124	DA 125	DA 127
7	18.0			PA 122	PA 122	DA 123	DA 124	DA 125	Site B Marsh 29 acres
8	21.0	New Upland Site	Site A Marsh 18.0 acres	Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	DA 127
9	24.0			Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	Site B Marsh 29 acres
10	27.0			PA 122	PA 122	DA 123	DA 124	DA 125	DA 127
11	30.0			PA 122	PA 122	DA 123	DA 124	DA 125	Site B Marsh 29 acres
12	33.0	New Upland Site	Site A Marsh 18.0 acres	Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	DA 127
13	36.0			Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	Site B Marsh 29 acres
14	39.0			PA 122	PA 122	DA 123	DA 124	DA 125	DA 127
15	42.0			Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	DA 127
16	45.0	New Upland Site	Site A Marsh 18.0 acres	PA 122	PA 122	DA 123	DA 124	DA 125	Site B Marsh 29 acres
17	48.0			Site A Marsh 20 acres	PA 122	DA 123	DA 124	DA 125	DA 127

Final approximate levee heights at the end of project. PA 127: +30 mlt, PA 127 El. +26 feet MLT

Table 3
Placement Plan for Maintenance Material
Reach 3 – Station 775+000 to Station 792+000

Cycle	Year	Sta. 775+000 to Sta. 785+000	Sta. 785+000 to Sta. 792+000
CY/Cycle		291,000	203,000
1	4.5	Site D Marsh 37 acres	Site E Marsh 32 acres
2	9	Site B Marsh 37 acres	DA 129
3	13.5	Site C Marsh 31 acres. Site B Marsh 7 acres	Site E Marsh 32 acres
4	18	DA 127	DA 129
5	22.5	Site B Marsh 37 acres	Site E Marsh 32 acres
6	27	DA 127	DA129
7	31.5	Site B Marsh 37 acres	Site E Marsh 21 acres, DA 129 11 acres
8	36	DA 127	DA 129
9	40.5	Site B Marsh 37 acres	DA 129
10	45	DA 127	DA 129
11	49.5	DA 127	DA 129

Final Approximate Levee heights at end of project:
DA 127: +30 mlt
DA 129: +30 mlt

Table 4

Placement Plan for Maintenance Material
Reach 4- Station 792+000 to 830+000

Cycle	Year	Station 792+000 To Station 805+000	Station 805+000 To Station 815+000	Station 815+000 To Station 830+000
CY/Cycle		256,100	82,600	159,900
1	1	Site E Marsh 21 acres, Site G Marsh 10 acres, DA 129	Site G Marsh 20 acres	Site I Marsh 25 acres
2	11	DA129	DA 130A	Site I Marsh 25 acres
3	22	DA 129	DA 130A	Site I Marsh 25 acres
4	33	DA 129	DA 130A	DA 130B
5	44	DA 129	DA 130A	DA 130B

Final approximate Levee heights at the end of the project:

DA 129: +30 mlt
DA 130A: +16 mlt
DA 130B: +15 mlt
DA 131: +26 mlt

Table 5

PLacement Plan for Maintenance Material
Reach 5- Station 830+000 to 839+000

Cycle	Year	Sta. 830+000 to Sta. 839+000	Sta. 839+000 to Sta. 843+000	Sta. 843+000 to Sta. 853+000	Sta. 853+000 to Sta. 860+000
CY/Cycle		340,900	180,000	261,000	196,600
1	3.5	Site K Marsh, 35 ac, DA 131	DA 132	DA 133	DA 134
2	7	DA 131	DA 132	DA 133	DA 134
3	10.5	Site J Marsh 53 acres	DA 132	DA 133	DA 134
4	14	DA 131	DA 132	DA 133	DA 134
5	17.5	Site J Marsh 53 acres	DA 132	DA 133	DA 134
6	21	DA 131	DA 132	DA 133	DA 134
7	24.5	Site J Marsh 53 acres	DA 132	DA 133	DA 134
8	28	DA 131	DA 132	DA 133	DA 134
9	31.5	Site I Marsh 53 acres	DA 132	DA 133	DA 134
10	35	DA 131	DA 132	DA 133	DA 134
11	38.5	Site I Marsh 53 acres	DA 132	DA 133	DA 134
12	42	DA 131	DA 132	DA 133	DA 134
13	45.5	DA 131	DA 132	DA 133	DA 134
14	49	DA 131	DA 132	DA 133	DA 134
15	52.5	DA 131	DA 132	DA 133	DA 134

Final approximate levee heights at end of project:

DA 131: +26 mlt ?, Graph shows fill height to +30'

PA 127

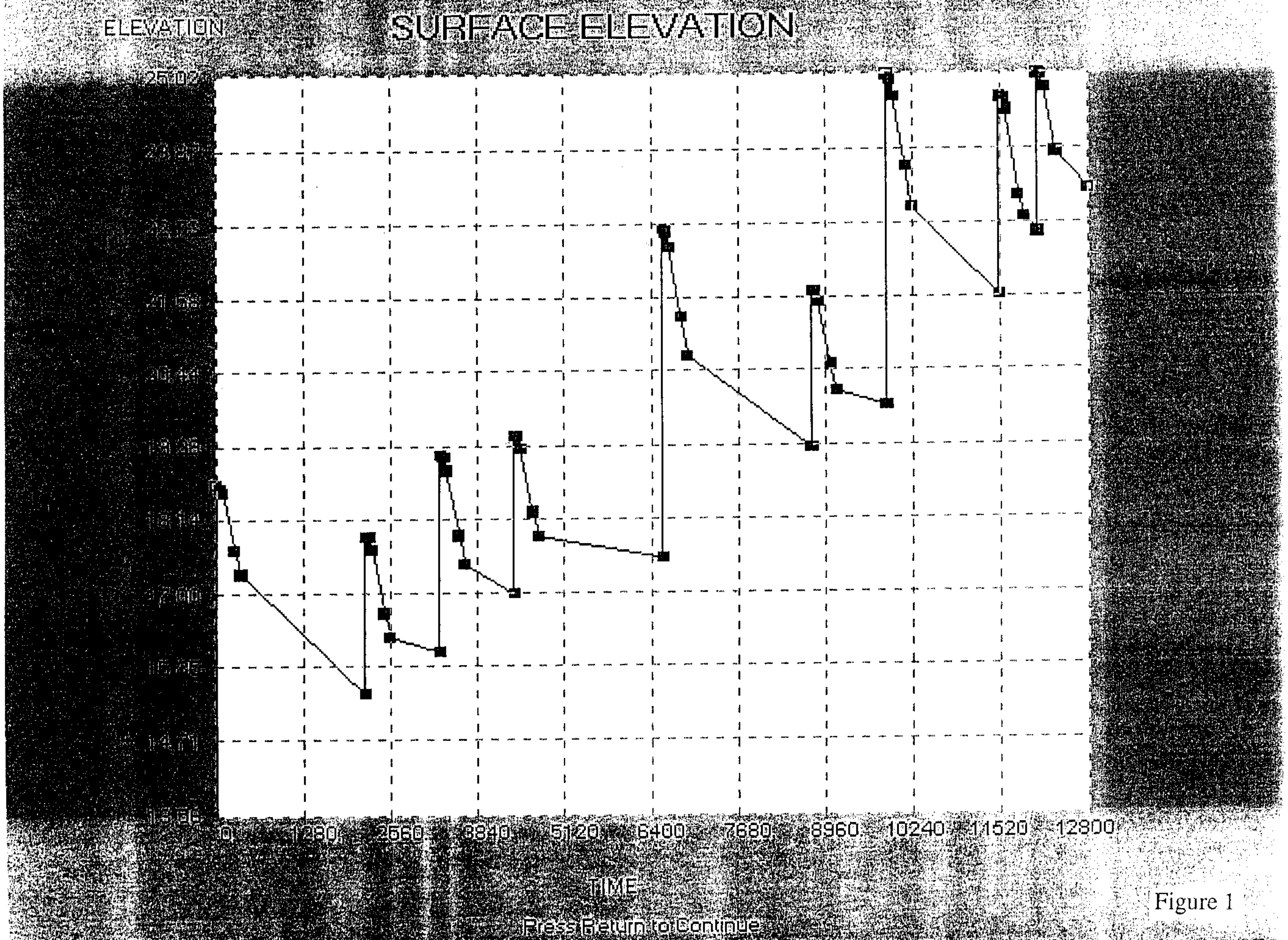


Figure 1

PA 129

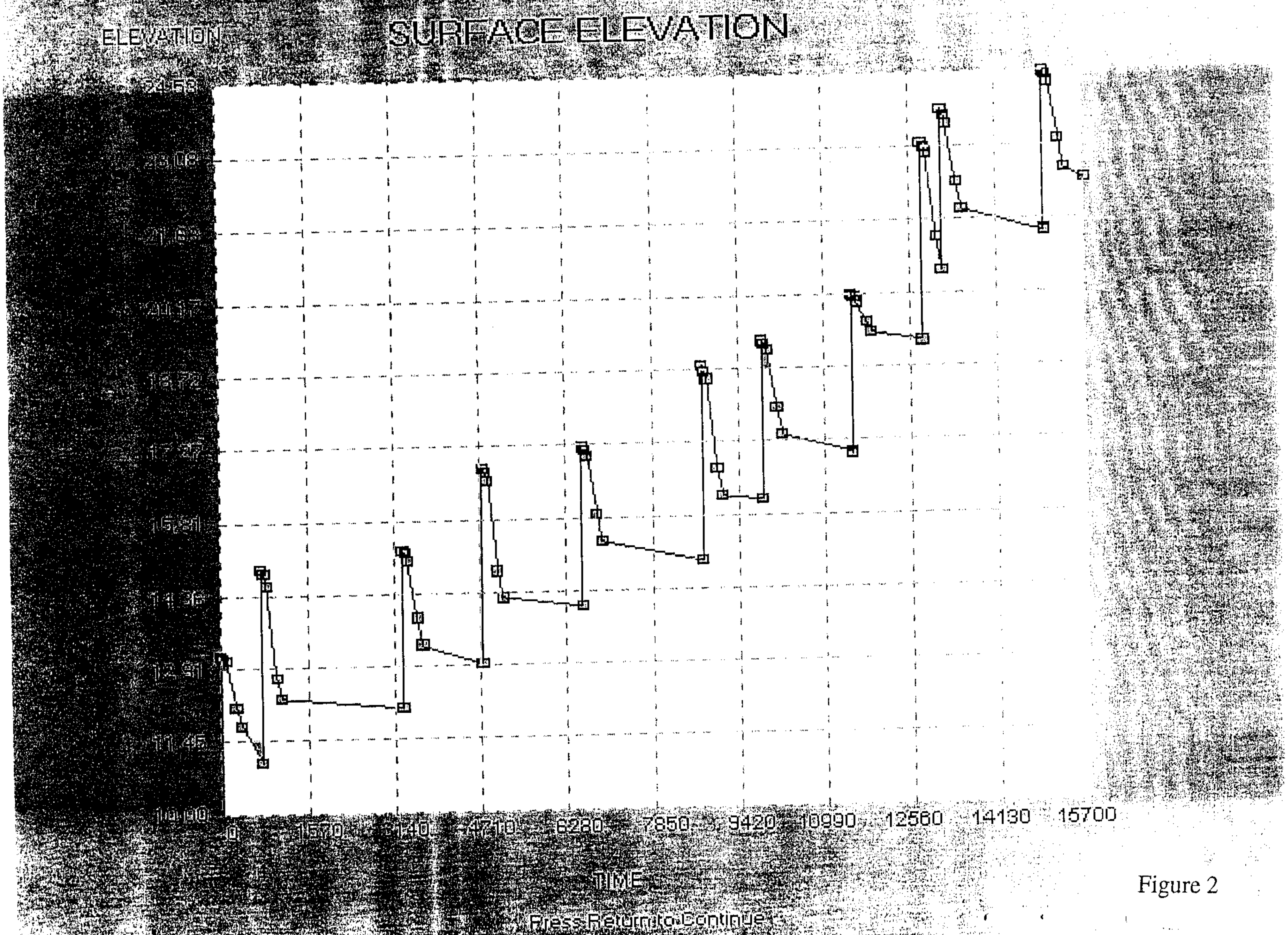


Figure 2

PA 130B

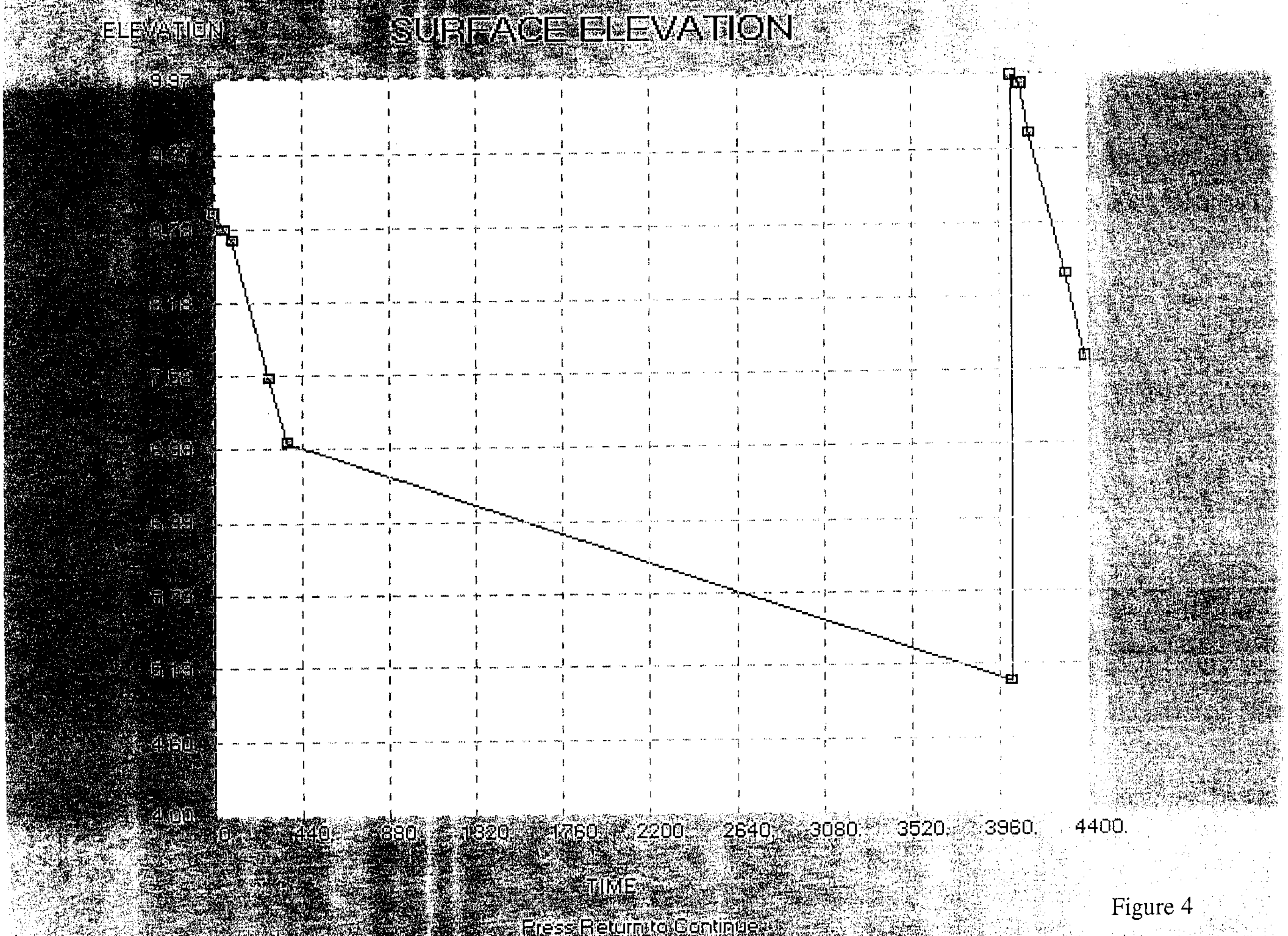


Figure 4

PA 131

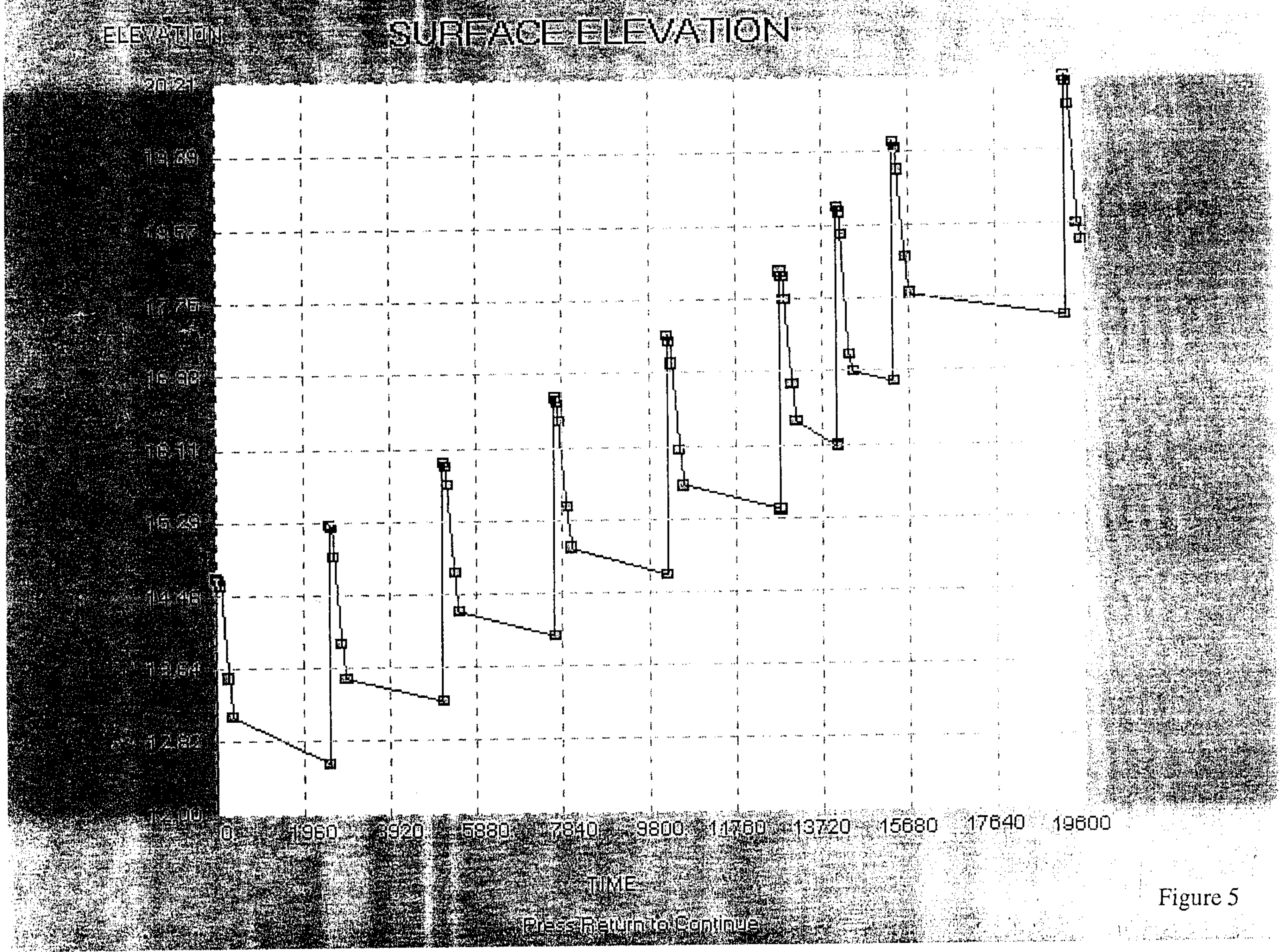
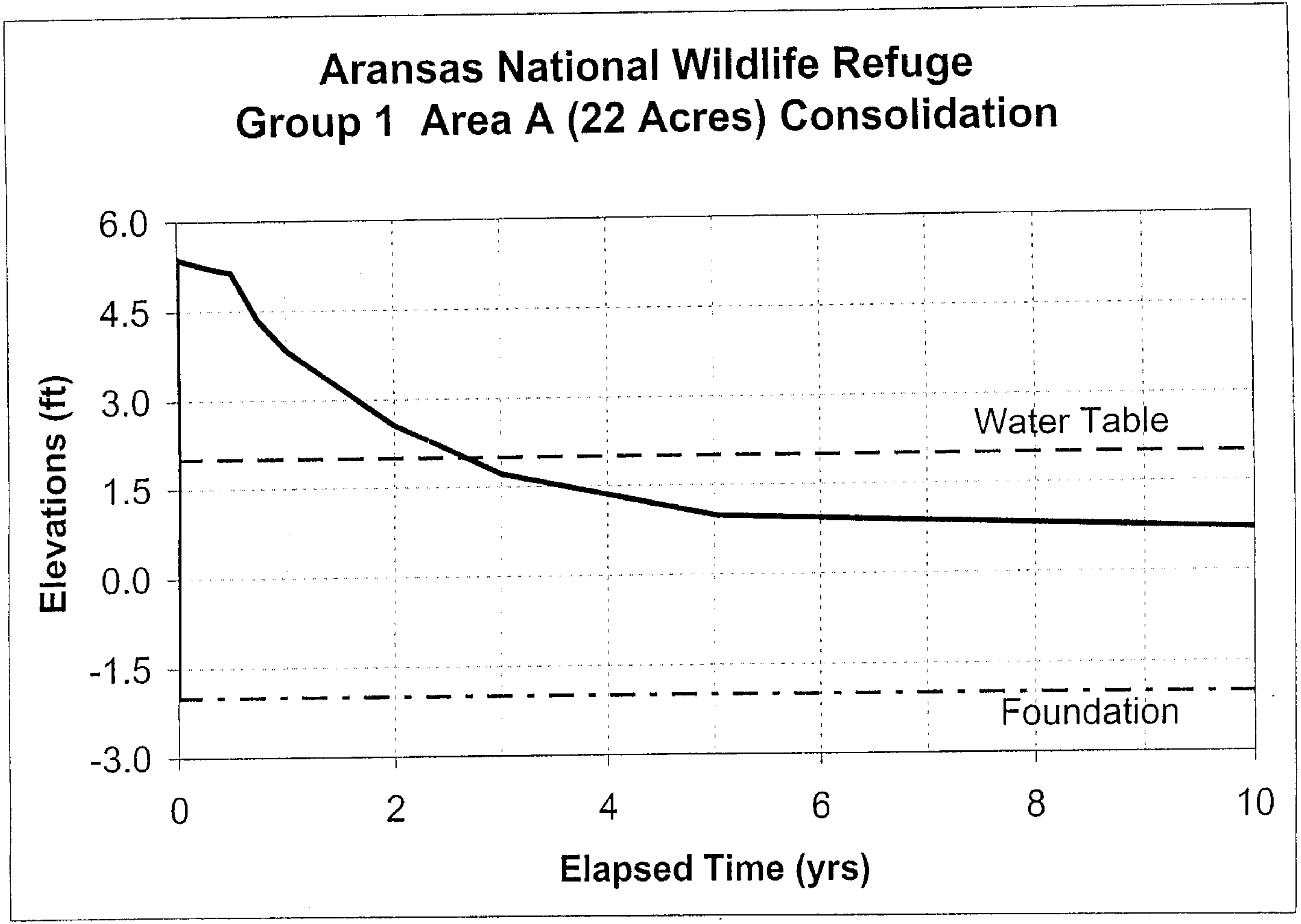


Figure 5



Aransas National Wildlife Refuge
Group 1 Area A (22 Acres) Consolidation
6.0
4.5
3.0
1.5
0.0
-1.5
-3.0
Elevations (ft)
Water Table
Foundation
0
2
4
6
8
10
Elapsed Time (yrs)

Figure 6

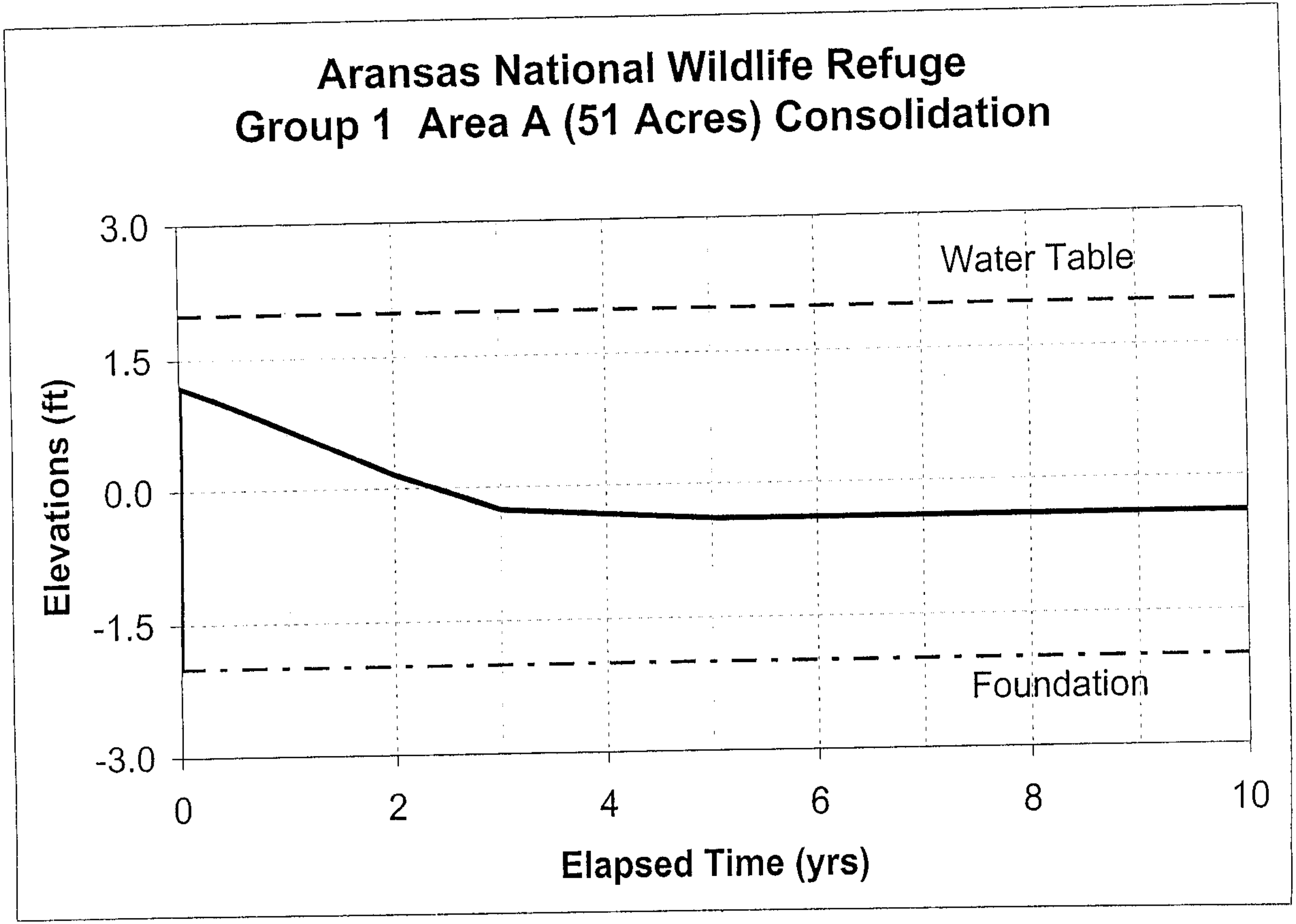
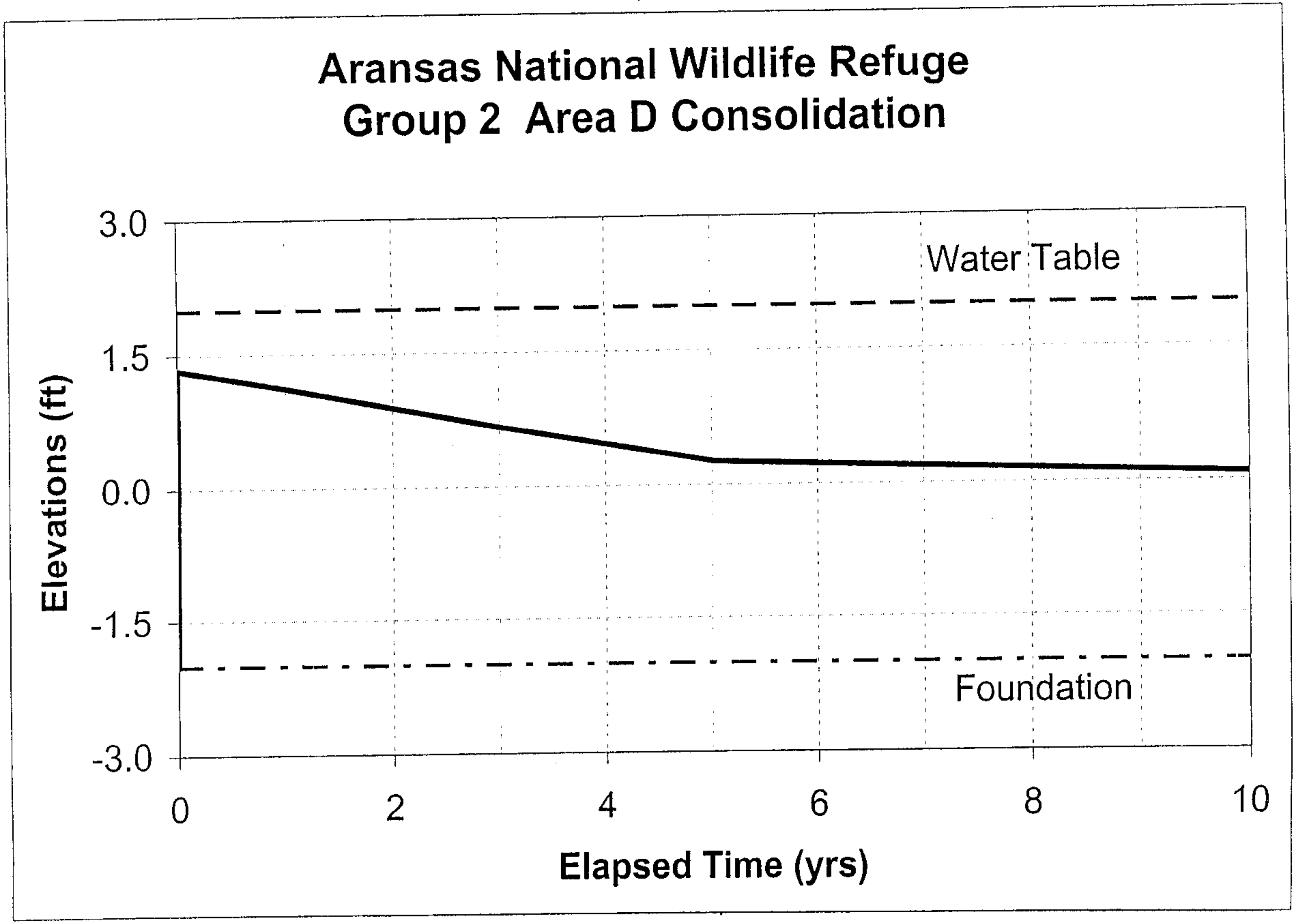

Aransas National Wildlife Refuge
Group 1 Area A (51 Acres) Consolidation
3.0
1.5
0.0
-1.5
-3.0
Elevations (ft)
Water Table
Foundation
0
2
4
6
8
10
Elapsed Time (yrs)

Figure 7



Aransas National Wildlife Refuge
Group 2 Area D Consolidation
3.0
1.5
0.0
-1.5
-3.0
Elevations (ft)
Water Table
Foundation
0
2
4
6
8
10
Elapsed Time (yrs)

Figure 8

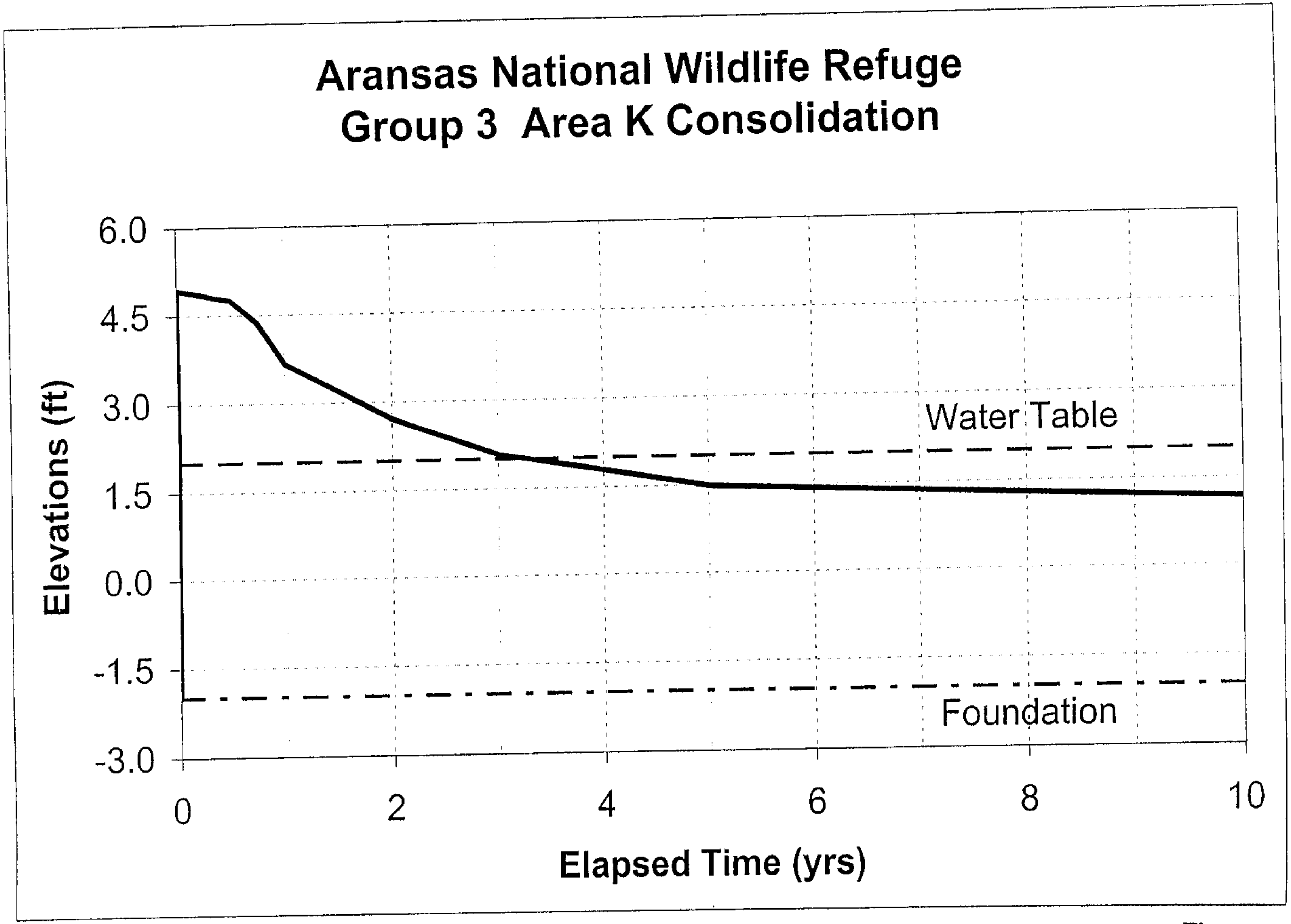

Aransas National Wildlife Refuge
Group 3 Area K Consolidation
6.0
4.5
3.0
1.5
0.0
-1.5
-3.0
Elevations (ft)
0
2
4
6
8
10
Elapsed Time (yrs)
Water Table
Foundation

Figure 9

4.2 <u>Beneficial Use Sites.</u> Forty-six borings, designated as borings 94-177 through 94-222, were drilled along the foundation of the 10 proposed BUS. The 10 proposed BUS are designated as BUS A through BUS K with the exclusion of BUS H. The exclusion of BUS H will be discussed in the paragraph BUS Design. All borings were drilled in shallow water from a barge. All borings were continuously sampled with 3-inch diameter Shelby tubes where clays were encountered. Where cohesionless materials were encountered, samples were taken with a split spoon during performance of Standard Penetration Testing. All samples were visually classified in the field and the consistency of the cohesive undisturbed samples was measured with a pocket penetrometer. Representative samples were tested in the laboratory for shear strength, classification, moisture content, unit weight, and Atterberg Limits. The BUS boring locations and logs of borings are shown on Exhibits C-1-1 through C-1-3 and C-3-1 & C-3-2.

4.3 <u>Dredged Maintenance Material</u>. Thirty-six disturbed sediment grab samples were collected from the GIWW channel bottom between Station 700+000 and Station 841+000 using a ponar dredge. All samples were visually classified in the field. Representative samples were tested in the laboratory for classification, grain size distribution, moisture content, unit weight, and Atterberg Limits. The above sediment samples were grouped into three material types based on sample locations and laboratory test results. The GIWW reach for Group 1 material is Station 724+000 to Station 730+000. The GIWW reach for Group 2 material is from Station 785+000 to Station 792+000. The GIWW reach for Group 3 material is from Station 830+000 to Station 839+000. Five 5-gallon buckets of disturbed sediment grab samples were collected of each of the three material types from their corresponding reaches for a total of fifteen samples. A 5-gallon water sample was collected from each of the three reaches. The 5-gallon sediment samples from each reach were mixed together to form a composite for a total of three composite samples. The composite samples were tested in the laboratory for self-weight consolidation, settling rates, void ratios with associated effective stresses, grain size distribution, classification, moisture content, unit weight, and Atterberg Limits. Grain size distribution curves of composite dredged material samples are shown in Exhibit C-4.

5.0 <u>Laboratory Testing</u>. All soil testing, for foundation conditions, was performed in accordance with EM 1110-2-1906, Laboratory Soils Testing. Visual classifications were made on all samples. Laboratory testing of typical samples of cohesive undisturbed materials consisted of determination of moisture content, unit dry weight, liquid limit, plastic limit, hydrometer and sieve analysis. For typical samples of cohesionless materials, only sieve analyses were performed. Laboratory testing of disturbed composite materials consisted of the above mentioned tests for cohesive and cohesionless materials plus self-weight consolidation test, and column settling test. Self Weight Consolidation test for soft fine grained dredged materials were performed in accordance with Technical Report GL-86-13, The Large Strain, Controlled Rate of Strain (LSCRS) Device for Consolidation Testing of Soft Fine Grained Soils. A summary of test results is shown on Exhibit C-5. Volume characteristics of the dredge materials, settling of suspended solids, were determined using Compression Column Settling test for fine grained dredged materials in accordance with EM 1110-2-5027. Test results are shown on Exhibit C-6. Undrained shear strengths of typical samples of cohesive materials were determined in the laboratory by performing unconfined compression tests and triaxial "Q" tests. Results of undrained shear strengths from unconfined compression tests and "Q" tests are shown on Exhibit C-7. sheets 1 through 3. Grain size distribution curves of composite dredge materials and representative foundation samples were determined in the laboratory by performing hydrometer and sieve analysis.

6.0 Upland Placement Areas Foundation Conditions. Wet rotary drilling was initiated at the beginning of drilling. Therefore, fluid levels were measured immediately after drilling and ranged from 1.5 feet to 4.0 feet depth below existing ground elevation. The average water surface elevation is +2.0 mlt. For design and analysis the groundwater table is estimated to be several feet above +2.0 mlt.

6.1 PA 127. Borings along the channel side of PA 127, borings nos. 94-173 and 94-175, indicate existing levee materials are predominately stiff to very stiff clays with an 8-foot to 12-foot sand layer encountered in the center of the slope. Borings along the bay side of PA 127, borings nos. 94-172, 94-175, and 94-176, indicated the existing levee materials are predominately soft clays with a 6-foot to 10-foot medium dense silty sand layer encountered toward the base of the levee. All borings indicate the existing perimeter levee is constructed on a foundation of predominately medium dense to dense silty sand except Boring 94-175, at the northeast corner of PA127, indicates a 6-foot layer of very soft sandy clay exists underneath a 10-foot medium dense silty sand layer.

6.2 PA 129. Borings along the perimeter levee, boring nos. 94-166 through 94-172, indicate existing levee materials to be loose silty sand for 2 to 4-feet surface layer underlain by predominately medium dense silty sand, except boring no 94-168 which indicated a sift silty clay. All borings indicate the existing perimeter levee is constructed on a 2-foot to 4-foot layer of very soft silty clay followed by a 10-foot to 12-foot layer of medium dense to dense silty sand.

6.3 PA 130A. Borings along the perimeter levee, boring nos. 94-163 through 94-165, indicate existing levee materials to be loose silty sand for 2 to 4-feet underlain by predominately medium dense silt sand. All boring indicate the existing perimeter levee is constructed on a 2 to 4-foot layer of very soft silty clay underlain by a 10 to 12-foot layer of medium dense to dense silty sand.

6.4 PA 130B. Borings along the perimeter levee, boring nos. 94-157 through 94-162, indicate existing levee materials to be predominately medium dense to dense silty sand with a 4 to 6-foot layer of loose silty sand at the crest surface. All borings indicate the existing perimeter levee is constructed on a foundation of medium dense to dense silty sand.

6.5 PA 131. The southeast and southwest portion of the placement area, is represented by boring nos. 94-152, 94-153, and 94-154 which indicate a levee height of 20 to 26 feet of very soft to soft clay underlain by a 6 to 8 foot foundation layer of medium dense silty sand underlain by a 6 to 8 foot layer of dense silty sand. The north half of the placement area, is represented by boring nos. 94-154 and 94-155 which depicted levee materials to be 10 to 20-foot of alternating layers of medium dense silty sand and stiff clays underlain by a 4 to 6 foot layer of soft clays. The foundation material consists of a 15 to 20 foot medium dense to dense silty sand layer.

7.0 Beneficial Use Sites Foundation Conditions.

7.1 BUS A . All BUS A borings, 94-157 through 94-162, indicate foundation materials to be predominately a very loose, silty, sand layer from 5 to 10 feet in depth underlain with a 4 to 6 foot layer of medium stiff to stiff, silty, clays.

7.2 BUS B. BUS B borings, 94-204 through 94-207, indicate the foundation materials to consist of a 6 to 10 foot very loose, silty sand underlain by 4 to 6 feet of very soft to soft, silty clay. BUS B borings, 94-208 through 94-215 indicate the foundation materials to consist of a 12 foot very loose to loose, sand.

7.3 BUS C. BUS C boring 94-203 indicates foundation materials to be predominately very soft sandy clay for a depth of 6 to 10 feet underlain by medium stiff, sandy, clay.

7.4 BUS D. All BUS D borings, 94-200 through 94-202, indicates the foundation materials to be predominately very loose to loose, silty, sand for a depth of 8 to 12 feet underlain by stiff, sandy, clay in boring 94-200.

7.5 BUS E. Borings 94-195 through 94-198 indicate the foundation materials to be predominately very loose to loose, silty, sand for a depth of 4 to 10 feet, underlain by 4 to 6 feet of medium dense clay. Boring 94-199 indicates the foundation materials in the northeast corner to consist of a 6 foot layer of very soft, silty clay undelain by a 4 to 10 foot layer of stiff, silty clay.

7.6 BUS F. BUS F borings, 94-190 through 94-194, indicate the foundation materials to consist of a 2 to 4 feet of very loose, silty sand underlain by 4 to 10 feet of stiff, silty clay.

7.7 BUS G. BUS G boring, 92-270, indicates the foundation material to consist of 5 feet of very loose, silty sand, underlain by a 7 feet of medium dense, silty sand.

7.8 BUS I. BUS I borings, 94-184 through 94-189 indicate the foundation materials to consist of 2 to 6 feet of very loose, silty sand underlain by 40 to 10 feet of medium dense, silty sand with intermittent layers of soft, silty clay.

7.9 BUS J. BUS J borings, 94-177 and 94-178 indicate the foundation materials to consist of 6 to 8 feet of very loose, silty sand underlain by 4 to 6 feet of sitff, sandy, clay with intermittent layers of soft, silty clay.

7.10 BUS K. BUS K borings, 94-179 through 94-181, indicate the foundation materials along the west side to consist of 6 to 8 feet of very loose, silty sand underlain by 4 to 6 feet of medium stiff to stiff, clay. Borings 94-182 and 94-183 indicate foundation conditions along the GIWW to consist of 4 to 6 feet of very loose, silty sand underlain with 6 to 8 feet of medium dense, silty sand.

8.0 Dredged Material Characteristics. A summary of the material characteristics is included in Table 8-1.

Table 8-1
Dredged Material Characteristics

Group	Description	Liquid Limit	Plastic Limit	Plasticity Index	Specific Gravity
1	Sandy Clay, gray	62	17	45	2.76
2	Sandy Clay, gray	69	19	50	2.75
3	Sandy Clay	62	16	46	2.77

Results of the column settling tests, self-weight consolidation tests, sieve analyses (including grain-size distribution curves), and Atterberg limits tests are included in Exhibit C-4, C-5, and C-6 of Appendix C.

Although samples were not collected for materials from Station 805+00 to Station 815+00 the material consists of a dense, poorly graded, fine sand. Material from this reach will be used to construct BUS G and will also be placed in PA 130a.

9.0 SETTLE and PSDDF Analysis.

The SETTLE program estimates the bulking of the material during the dredging and placement process. The bulking of the material is used to determine the fill height and levee heights for the quantity of material bring dredged. The SETTLE program determines the volume characteristics of the dredge material. Additionally, the SETTLE computer program was used to determine the cyclic and final levee heights and compute the depth of placement storage required for the Upland Placement Sites and the final elevation of the material in both the upland and beneficial use sites. The initial SETTLE run used void ratios computed from the column settling test and self weight consolidation test results which represents the dredge material insitu in the channel. The SETTLE program was rerun using the concentration of fines at the end of disposal generating placed volume and bulking factor to compute new void ratios for the placement cycle. The new void ratios were entered into PSDDF computer program. The PSDDF computer program was used to determine the rate of self-weight consolidation and desiccation of the placement material which begins at the point of effluent decant and occurs for the time interval between dredging cycles as shown on the graph tables. The PSDDF computer program is used for computing the capacity of the confined placement area. For the PSDDF analysis of the upland sites the foundation was considered to be a compressible foundation from previous dredge placements. Void ratios were developed for these compressible foundations assuming the previous placements had reached 100% desiccation. This assumption is based upon running PSDDF for a single placement until 100% desiccation is reached and comparing the time (in years) it takes to reach desiccation to the time (in years) until the first placement cycle scheduled in the 50-year plan. Initial PSDDF runs were performed assuming a compressible foundation for the BUS also. Void ratios were computed using the laboratory test results from the BUS foundation areas and input into PSDDF. PSDDF results consistently yielded negligible foundation compression, between 1/4th of a foot to

½ of a foot, elevation differences. The final PSDDF analyses were performed assuming foundations to be incompressible.

10.0 Soil Strength Determination. Undrained shear strengths of cohesive materials were used in the slope stability analyses for the end of construction condition. These shear strengths were derived from the results of unconfined compression tests and unconsolidated undrained triaxial compression tests. Consolidated undrained shear strengths of representative cohesive materials were also used in slope stability analyses for the end of construction condition. Plots of the shear strength versus depth for materials of similar consistencies were made and are presented in Exhibits C-7, of Appendix C. A straight line representing the selected design strengths was plotted such that approximately two thirds of the test results exceeded the design strength for the end of construction condition. The shear strengths of cohesionless soils, silts and sands, is based on correlations between blow counts and angle of internal friction. The shear strengths of dense silty sands and sandy silts were conservatively selected to have a phi angle of 32 and 34 degrees, respectively. For long term slope stability analysis, the shear strengths of cohesive materials was based on typical values for the consistency of the material. For cohesionless soils, silt and sands, shear strength was based on correlations between blow counts and angle of internal friction. For fissured or slickensided clays, ultimate shear strengths were assumed to be 100 psf with a phi angle of 13 degrees. The design strengths for the long term loading and end of construction loading conditions are presented in Table 10-1.

Table 10-1
Design Shear Strengths

Soil Types	Long Term Loading Phi (Degrees)	End of Construction Loading C (psf)
Intact Shallow Clay (CH)	26	500
Intact Deep Clay (CL)	33	1000
Soft Silty Clay (CH)	24	300
Very Soft Silty Clays (CH)	20	90
Slicken sided Clays (CH)	13	100
Dense Silty Sand (SM)	30	30
Very Deep Dense Silty (SM)	34	34

11.0 Slope Stability Analysis. The design of the final perimeter levee heights for the next 50 years is partially determined using slope stability analysis. Analyses were performed at each upland Placement Area location along the GIWW channel reach. Stability of the existing slope conditions, and proposed final levee slopes were analyzed in selected locations considered to be most critical sections, which are the borings which indicate the material to be soft clays and loose sands. These critical locations generally occur near the drop-outlet structures or on the channel side of the Upland Placement Areas. The analyses were performed for the end of construction condition using the design shear strength derived from plots of unconsolidated undrained shear strengths as described in paragraph 10.0. For the long term condition, the analyses considered the design strengths presented in Table 10-1. A circular arc failure plane was assumed in the computer program UTEXAS2, which uses the Spencer's procedure for the computation of the factor of safety. The slopes of the levees used in the analyses were assumed to be 1V on 3H for both the existing condition and the proposed final elevation. A typical slope stability analysis performed at PA 131 Station 835+603 is presented in Exhibit C-8 of Appendix C.

12.0 Upland Site Design. The design of the perimeter levee heights and the placement and consolidation of the channel maintenance material for the next 50 years was analyzed using SETTLE, PSDDF, and UTEXAS2. Final analysis and designs is discussed in the following paragraphs.

12.1 PA 127. PA 127 is an approximately 86 acre site adjacent to the GIWW. The placement plan design was conducted using test results of Group 2 maintenance material. Table 12-1 summarizes the placement plan for PA 127.

Table 12-1
PA 127 Placement Plan

Year	Quantity (CY)	Fill Height (ft.)
6	227,000	2.4
12	227,000	2.4
18	518,000	5.1
24	227,000	2.4
27	291,000	3.1
30	227,000	2.4
36	518,000	5.1
42	227,000	2.4
45	518,000	5.1
49	291,000	3.1
51	227,000	2.4

The fill surface elevation throughout the 50 years of placement is shown in Figure 1. The final levee height including a freeboard of 2 feet and ponding depth of 3 feet will be approximately 30 feet with 1 vertical on 3 horizontal side slopes. Slope stability analyses were performed at GIWW Station 778+200 for the end-of-construction condition and long term loading conditions. A factor of safety of 1.37 was calculated for the end-of-construction condition.

12.2 PA 129. PA 129 is an approximately 60 acre site adjacent to the GIWW. The placement plan design was conducted using test results of Group 2 maintenance material. Table 12-2 summarizes the placement plan for PA 129.

Table 12-2
PA 129 Placement Plan

Year	Quantity (CY)	Fill Height (ft.)
9	203,000	3.1
11	256,100	3.6
18	203,000	3.1
22	256,100	3.6
27	203,000	3.1
33	256,100	3.6
36	203,000	3.1
40.5	256,100	3.6
44	203,000	3.1
45	256,100	3.6
49.5	203,000	3.1

The fill surface elevation throughout the 50 years of placement is shown in Figure 2. The final levee height including a freeboard of 2 feet and ponding depth of 3 feet will be approximately 30 feet with 1 vertical on 3 horizontal side slopes.

12.3 PA 130A. PA 130A is an approximately 43 acre site adjacent to the GIWW. The placement plan design was conducted assuming the maintenance material will consist of predominately sand materials. Table 12-3 summarizes the placement plan for PA 130A.

Table 12-3
PA 130A Placement Plan

Year	Quantity (CY)	Fill Height (ft.)
11	82,600	1.2
22	82,600	1.2
33	82,600	1.2
44	82,600	1.2

The final levee height including a freeboard of 2 feet and ponding depth of 3 feet will be approximately 25 feet with 1 vertical on 3 horizontal side slopes.

12.4 PA 130B. PA 130B is an approximately 129 acre site adjacent to the GIWW. The placement plan design was conducted using test results of Group 3 maintenance material. Table 12-4 summarizes the placement plan for PA 130B.

Table 12-4
PA 130B Placement Plan

Year	Quantity (CY)	Fill Height (ft.)
33	159,900	1.1
44	159,900	1.1

The fill surface elevation throughout the 50 years of placement is shown in Figure 4. The final levee height including a freeboard of 2 feet and ponding depth of 3 feet will be approximately 15feet with 1 vertical on 3 horizontal side slopes. Slope stability analyses were performed at GIWW Station 835+603 for the end-of-construction condition and long term loading conditions. The factor of safety of 1.38 for both end-of-construction and long term loading conditions.

12.5 PA 131. PA 131 is an approximately 103 acre site adjacent to the GIWW. The placement plan design was conducted using test results of Group 3 maintenance material. Table 12-5 summarizes the placement plan for PA 131.

Table 12-5
PA 131 Placement Plan

Year	Quantity (CY)	Fill Height (ft.)
7	340,900	2.7
14	340,900	2.7
21	340,900	2.7
28	340,900	2.7
35	340,900	2.7
42	340,900	2.7
45.5	340,900	2.7
49	340,900	2.7
52.5	340,900	2.7

The fill surface elevation throughout the 50 years of placement is shown in Figure 5. The final levee height including a freeboard of 2 feet and ponding depth of 3 feet will be approximately 26 feet with 1 vertical on 3 horizontal side slopes. Slope stability analyses were performed at GIWW Station 835+603 for the end-of-construction condition and long term loading conditions. The factor of safety of 1.38 for both end-of-construction and long term loading conditions. The results of the stability analysis are shown graphically in Exhibit C-8 of Appendix C.

13.0 Beneficial Use Sites Design. The design of BUS A through K is discussed detailed in Appendix B, General Design and Construction Considerations. Test results from Group 1 material was use to design BUS A. Test results from Group 2 material was used to design BUS B, BUS C, BUS D BUS E, BUS F. Test results from Group 3 material was used to design BUS G, BUS I, BUS J and BUS K.

Gulf Intracoastal Waterway
Aransas National Wildlife Refuge
Dredged Material Management Plan

Appendix A

Goals of the Beneficial Use Sites

Purpose of this Report

This report provides planning information relevant to wetland creation using dredged material as part of the Gulf Intracoastal Water–Aransas National Wildlife Refuge 50-year Dredged Material Management Plan (DMMP). This document is divided into several sections:

- Summary of Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Measures for the Gulf Intracoastal Waterway-Aransas National Wildlife Refuge (ANWR) 50-year Dredged Material Management Plan;
- Investigations: Elevation, Vegetation, and Landscape-level Geomorphology;
- Testing Vegetation Performance Standards with Field Data
- Conceptual Design: Self-organizational Theory and Site Designs, Adaptive Management, Planting, Structures, and Coordinating dredging cycles;
- Specific designs for Beneficial Use Sites A, D, and K (as per *Gulf Intracoastal Waterway–Aransas National Wildlife Refuge, Texas, Feasibility Report and Final Environmental Impact Statement*); and
- Implementing Designs.

Figure 1 gives ground-level views of habitat at the project site.

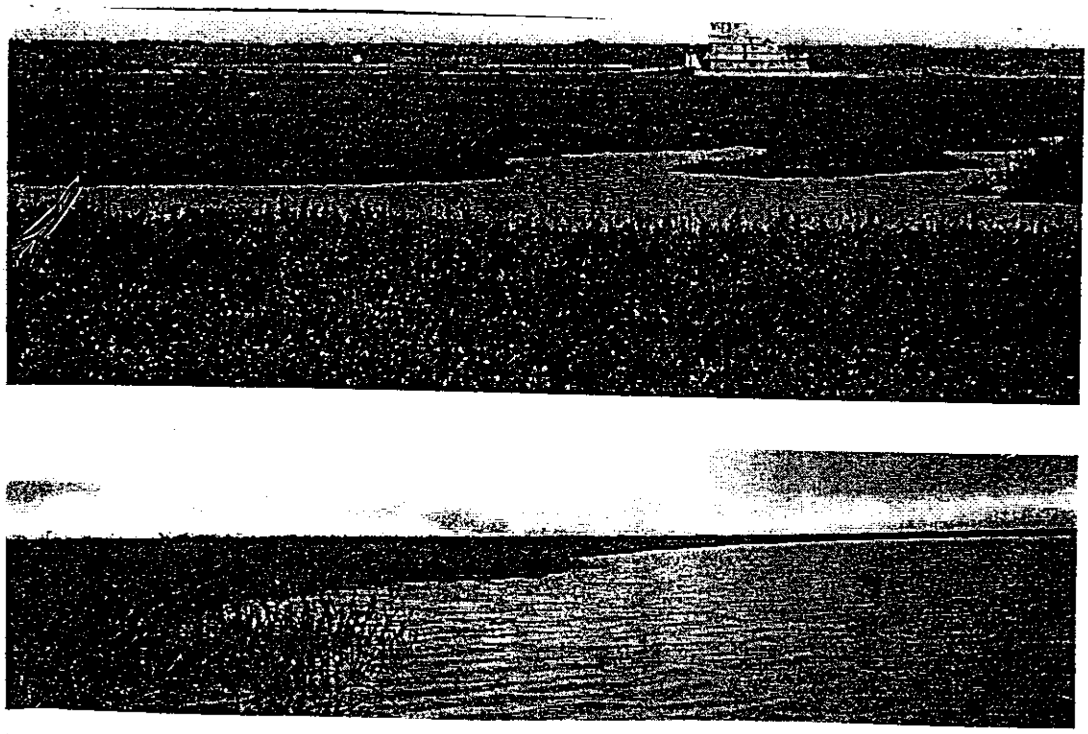


Figure 1. Marsh habitat in the project area. High marsh species dominate most of the project area (top), although *Spartina alterniflora* occurs in scattered patches, mostly along marsh edges (bottom).

I. Summary of Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Measures for the Gulf Intracoastal Waterway-Aransas National Wildlife Refuge 50-year Dredged Material Management Plan

This section summarizes the outcome of discussions of the Aransas Interagency Coordination Team (ICT) meetings on 3-4 November 1998 and 6 April 1999 regarding the creation of wetlands as part of the 50-year Dredged Material Management Plan (DMMP) for the Aransas National Wildlife Refuge stretch of the Gulf Intracoastal Waterway, including the Welder Flats area. Discussions began with the assumption that 1,613.5 acres of wetland habitat would be created from dredged material at specific locations labeled A-K (Figure 2), as per the *Gulf Intracoastal Waterway-Aransas National Wildlife Refuge, Texas; Feasibiilty Report and Final Environmental Impact Statement*. Furthermore, it was understood that marsh creation would occur in conjunction with maintenance dredging cycles scheduled throughout the 50-year life of the DMMP (Table 1).

Table 1. Schedule for site creation*. See Figure 2 for site locations. The "year" is the year from beginning of 50-year DMMP. The parenthetical "cumulative acres" is the cumulative acres for each site. Bold type represents final planned acreage for each site. Total planned acreage for all sites combined is 1,613.5 acres.

Site	Year	Acres (Cumulative acres)	Site	Year	Acres (Cumulative acres)
A	2.5	42 (42)	D	4	90 **(90)**
A	5	42 (84)	E	4	49 (49)
A	7.5	18.5 (102.5)	E	12	49 (98)
A	10	42 (144.5)	E	20	49 **(147)**
A	12.5	42 (186.5)	F	12	24 (24)
A	17.5	42 (228.5)	F	20	24 (48)
A	20	42 (270.5)	F	28	24 (72)
A	22.5	18.5 (289)	F	36	24 **(96)**
A	25	42 (331)	G	4	24 **(24)**
A	27.5	42 (373)	H	4	10 **(10)**
A	37.5	18.5 **(391.5)**	I	4	37 (37)
B	12	47 (47)	I	12	37 (74)
B	20	90 (137)	I	28	74 (148)
B	28	90 (227)	I	36	74 **(222)**
B	36	90 (317)	J	12	74 (74)
B	44	90 **(407)**	J	20	74 **(148)**
C	12	43 **(43)**	K	4	35 **(35)**

*This information should be updated as final values are developed.

ICT discussions focused on establishment of guidelines for the wetland creation portion of the

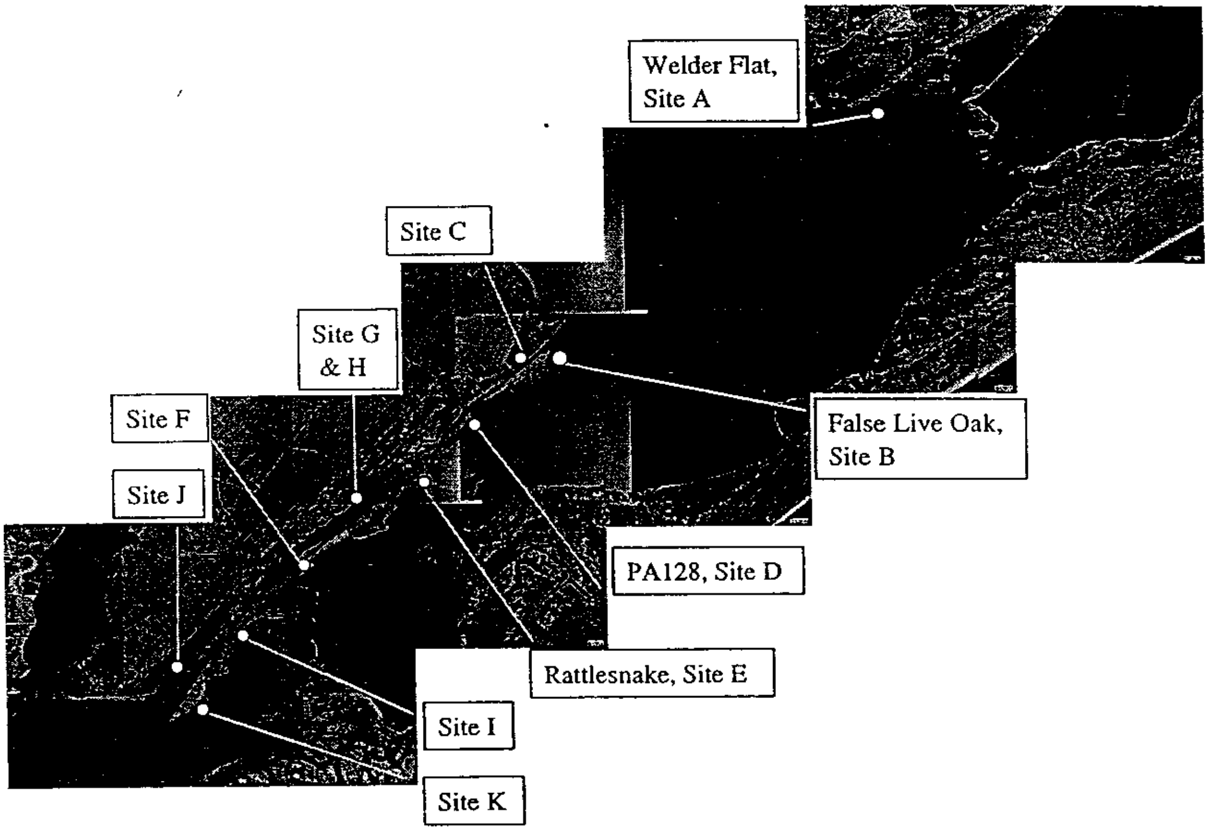


Figure 2. Planned marsh creation sites near Aransas National Wildlife Refuge, Texas.

50-year DMMP, including establishment of appropriate goals, objectives, performance standards, monitoring methods, and remedial measures. Topics such as justification of this project and funding opportunities were also discussed.

Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Measures

Table 2 defines goals, objectives, performance standards, monitoring methods, and remedial measures in the context used in this report.

Table 2. Definitions of terms used in wetland creation planning, in the context of this report.

Term	Definition
Goals	General statement about desired project outcomes; stating a goal allows all stakeholders to understand, in general terms, the desired direction of the project
Objectives	Specific statements about desired project outcomes; projects typically have more than one objective
Performance standards	Observable or measurable attributes that can be used to determine if a wetland creation project meets the objectives intended for the project; each objective will have one or more associated performance standards
Monitoring methods	Specific approaches to determining if performance standards have been met
Remedial action	Actions to be taken if performance standards are not met within the desired period

Goals, objectives, performance standards, monitoring methods, and remedial actions for the 50-year DMMP were discussed and agreed upon by ICT members attending the 3-4 November 1998 ICT meeting, which was largely dedicated to a workshop intended for development of these goals, objectives, performance standards, monitoring methods, and remedial actions. At the 6 April 1999 ICT meeting, minor changes to goals, objectives, performance standards, monitoring methods, and remedial actions were discussed and approved. Table 3 summarizes final goals, objectives, performance standards, monitoring methods, and remedial actions for wetland sites to be created as part of the 50-year DMMP. Note that two of the vegetation community performance standards (the Similarity Performance Standard and the Diversity Performance Standard) and approaches to aerial photography were modified based on testing described in this report (see "Section III. Testing Vegetation Performance Standards with Field Data"), as per the comments appended to Table 3.

Table 3. Summary of goals, objectives, performance standards, monitoring methods, and remedial measures from the 3-4 November ICT meeting.

Goal	Objectives	Performance standard	Monitoring method	Remedial measure
Use dredged material to create marsh similar to nearby natural marshes[1], including both high and low marsh, without adversely impacting critical habitats and while minimizing impacts to other natural habitats, and without adversely impacting navigation requirements	Provision of habitat for Whooping Cranes	Presence of at least one Whooping Crane per 200 ha of created marsh, on average, during the wintering season	Aerial counts of Whooping Cranes as part of USFWS routine weekly aerial counts and ground observations 7 years after marsh creation	Investigations designed to determine why Whooping Cranes are not using the habitat should be undertaken, including determination of similarity of created marsh to natural marsh, and results of these studies should be considered in marsh design as part of future dredging cycles
	Stabilization of dredged material	Areal loss of marsh should be no more than 10% of initial marsh area for the life of the project	DOQQs or equivalent photography at a scale of 1:1500 should be assessed at least once every 7 years to establish changes in area of marsh[2]	Erosion problems to be arrested by repairing or altering structures as needed, or by installation of additional structures
			At least once each year, structural integrity of earthen dikes and other structures intended to stabilize dredged material will be assessed	Consider additional placement of dredged material on eroding site
				Consider and correct design flaws that might impact sites created as part of future dredging cycles
	Accommodate required volume of dredged material	Projected capacity available as per maintenance dredging schedule[3]	Requirements established in preplacement surveys will be compared to design capacities stated in 50-year DMMP	Modify designs in DMMP as needed to accommodate changes in projected volume of dredged material

1. Natural marsh to be included extends about 1,000 feet inland from existing marsh edge.

2. During discussions with the ICT, use of photographs taken at a scale of 1:1000 were tentatively suggested. After further discussions with USGS remote sensing personnel, use of 1:1000 aerial photographs was discarded in favor of DOQQs, which have a resolution of 1 m.

3. Estimates of minimum and maximums of maintenance dredging needs are reported elsewhere in the 50-year DMMP.

Table 3. Summary of goals, objectives, performance standards, monitoring methods, and remedial measures from the 3-4 November ICT meeting **(continued)**.

Goal	Objectives	Performance standard	Monitoring method	Remedial measure
Use dredged material to create marsh similar to nearby natural marshes, including both high and low marsh, without adversely impacting critical habitats and while minimizing impacts to other natural habitats, and without adversely impacting navigation requirements	Support vegetation communities similar to those typical of nearby natural marshes	No *Phragmites australis* or obligate upland plants	Site visits to observe occurrence of undesirable plant species at least once per year, with upland plants as defined by USFWS plant lists	Removal or herbiciding of undesirable vegetation
		At least 1/5 of total cover (inclusive of bare ground) will be by *Batis maritima*, *Borrichia frutescens*, *Monanthochloe littoralis*, *Salicornia* spp., and *Lycium carolinanum*, and *Lycium carolinanum* will be present[4]	Collection of areal % cover data from at least 40 1-m^2 quadrats at created wetland 3 years after wetland planting, with quadrats placed randomly within the created wetland	Consider recontouring to support appropriate vegetation communities
				Consider remedial planting
		Similar patchiness in created and natural marsh sites as determined by achieving mean Shannon-Wiener Diversity Index values within 1-m^2 plots in created wetlands that is within the range of mean diversities for 1-m^2 plots in 5 nearby natural wetlands[5]	Collection of areal % cover data from at least 40 1-m^2 quadrats at created wetland and 5 nearby natural wetlands 3 years after wetland planting and computation of mean Shannon-Wiener Diversity index scores for created and natural wetlands	Consider and correct design flaws that led to low vegetation similarity or dissimilar patchiness
	Protect and preserve contiguous habitat	ICT members offer no negative observations or reports regarding impacts to contiguous habitat	Observations to be undertaken as part of routine site visits at least once per year	Seek ICT recommendations

4. This performance standard replaces the similarity performance standard discussed at the 3-4 November 1998 ICT meeting. The similarity performance standard was discarded after testing indicated that it was not appropriate. See "Section III. Testing Vegetation Performance Standards with Field Data" of the report.

5. ICT discussions led to suggestion of use of mean diversities as a measure of vegetation patchiness, or intermixing of species. ICT discussions suggested that diversity values should be wihtin 50% of those found in nearby natural wetlands, but testing of this method showed that it would be more appropriate to base the performance standard on attainment of a diversity within the range of those found in nearby natural wetlands. See "Section III. Testing Vegetation Performance Standards with Field Data" of this report.

Table 3. Summary of goals, objectives, performance standards, monitoring methods, and remedial measures from the 3-4 November ICT meeting **(continued)**.

Goal	Objectives	Performance standard	Monitoring method	Remedial measure
	Avoid creation of or increase in navigation problems or changes to dredging volume and frequency	No negative feedback through the ICT	Observations each year from Corps of Engineers conditions surveys, intracoastal waterway users, or others	Seek ICT recommendations
Use dredged material to create marsh similar to nearby natural marshes, including both high and low marsh, without adversely impacting critical habitats and while minimizing impacts to other natural habitats, and without adversely impacting navigation requirements	Develop habitat for fisheries support	Edge:area ratio equal to or greater than the median edge:area ratios of nearby natural marsh sites	Created wetland DOQQs or equivalent photography at a scale of 1:1500 should be interpreted once every 7 years and edge:area ratio compared to that typical of 5 nearby natural marshes	Where practicable, additional dredged material placement or recontouring should be used to obtain appropriate edge:area ratios, slopes, elevations, and open water habitat connected to tidal flushing, or edge:area ratios, slopes, elevations, and open water habitat connected to tidal flushing should be adjusted at marshes created as part of future dredging cycles for compensation
		Area of open water habitat with connection to tidal flushing is equal to or greater than median areas of open water habitat with connection to tidal flushing in nearby natural marsh sites	DOQQs or equivalent photography at a scale of 1:1500 will be used to measure area of open water once per 7 years and percent of marsh area comprised of open water habitat with tidal connections will be compared to that typical of 5 nearby natural marshes	For sites to be created as part of future dredging cycles, consider and correct design flaws that led to inappropriate edge:area ratios, slopes, elevations, and open water habitat connected to tidal flushing
		Slopes and elevations within the range of those typical of nearby natural marsh sites	A minimum of five transects will be surveyed at each created wetland and at 5 nearby natural wetlands once per 7 years, and slopes and elevations of transects at created wetlands will be within the range of those typical of nearby natural marshes	
		Mean overall density of blue crabs, transient fish species, and resident fish species in created wetlands are not to be significantly different from means for nearby natural wetlands[6]	Fish censusing via trapping (drop traps or throw traps, but not minnow traps, breder traps, or similar semi-quantitative methods) with a reasonably powerful sampling design will be used to compare mean densities 7 years after wetland creation at each site	Investigations should be undertaken to determine why differences exist in mean densities of blue crabs, transient fish, and resident fish

6. Measurement of blue crab and fish densities will require significant funding and will only be undertaken if funding is available. If measurements of blue crab and fish densities are not possible because of funding limitations, habitat structure variables will be accepted as a "stand-alone" measure of fisheries habitat development.

Development of goals, objectives, performance standards, monitoring methods, and remedial actions is not a simple process. It relies on professional judgement and experience from a number of fields. During the 3-4 November 1998 ICT meeting, a number of possible goals were discussed. After initial discussion, goals focused on using dredged material to 1) establish marsh similar to nearby natural marshes and 2) establish marsh generally similar to natural marsh, but with certain enhancements, such as increased areas of *Spartina alterniflora* edge habitat that would support certain fish species and provide some protection from wave energy to high marsh habitat. After further discussion, it was decided that the goal of marsh creation would be establishment of marsh similar to nearby natural marshes, but with an emphasis on emulating natural marshes with reasonably high levels of edge habitat. The emphasis on emulating natural marshes with reasonably high levels of edge habitat is reflected in performance standards related to the objective of fish habitat development (Table 3). During discussions of goals and objectives, it was also noted that marsh creation should not adversely impact existing critical natural habitat, should minimize impacts to other natural habitats, and should not adversely impact navigation requirements.

The guidelines generated by the ICT will require marsh construction efforts exceeding those routinely used in creation of salt marsh habitat as part of the beneficial use of dredged material, including efforts used in creation of the demonstration marshes at Placement Areas 127A and 128. Creation of marshes with characteristics described in guidelines will require 1) special care to achieve target elevations, 2) development of innovative techniques to cost-effectively create topographic characteristics similar to those of natural marshes, and 3) planting efforts focused on achieving the biodiversity, density, and species patchiness characteristic of nearby natural marshes. In addition, guidelines call for extensive monitoring.

Changing Goals, Objectives, Performance Standards, Monitoring Methods, and Remedial Actions

Information in Table 3 will allow the Corps to move forward with design of sites for the DMMP, but Table 3 should be revisited periodically by the ICT as the DMMP is implemented. Problems with project design, changes in technology, changes in the perceived desirable characteristics of created wetlands, or other developments may arise that will render some or all of the information in Table 3 obsolete. However, revision of goals, objectives, performance standards, monitoring methods, and remedial actions should not be taken lightly. Experience has shown that people can lose sight of guidelines midway through projects or after projects are completed, and that periodic review of guidelines can prevent wasted effort and contentious claims of success or failure. ICT members agreed that changes to goals, objectives, performance standards, monitoring methods, and remedial actions should be specifically approved by the ICT.

Justification of Effort

During discussions, the ICT recognized that the wetland creation effort under consideration as part of the 50-year DMMP was unusually ambitious. Because these sites will be created adjacent to the Aransas National Wildlife Refuge, the extra effort required to satisfy goals, objectives, and performance standards can be justified. The created wetlands are likely to provide habitat for endangered Whooping Cranes and will undoubtedly attract the attention of conservation organizations and the general public. Also, techniques developed for creation of these marshes can be used in future wetland creation programs at other sites and may contribute to substantial improvements in salt marsh creation using dredged material throughout the United States.

Funding Opportunities

ICT members expressed concern about the possibility of designs being "scaled back" because of increased costs associated with innovative design requirements. Until detailed designs are completed (i.e., when dredging is scheduled), it is impossible to estimate the magnitude of costs. However, if costs restrict the ability of the Galveston District to support the desired design, ICT members suggested that opportunities for cost sharing should not be overlooked. Because the project will extend over 50 years, ICT members believed that external support could be attracted for at least some aspects of the required work. ICT members supported the possibility of seeking funds from non-Corps sources, if necessary.

Several potential sources for funding or in-kind support were identified, including: 1) Section 204, 1135, and 206 funds, 2) Texas Coastal Management Program funds, via the Texas Coastal Coordination Council, and 3) in-kind support for site development as part of a compensatory mitigation requirement through Section 404 of the Clean Water Act. Other sources of funding may be available to supplement aspects of project construction. Corps of Engineers funding support mechanisms for wetland creation and restoration projects are summarized in Text Box 1. This summary of information was not discussed by the ICT, but is included here as supplemental information.

Immediate Needs Recognized by ICT

To proceed with design of sites based on identified goals and objectives in Table 3 and to test a number of points considered as part of project guidelines, the necessity of collecting limited field and photographic data was recognized. Critical requirements discussed were:

- high-accuracy (±5 cm) topographic measurements of selected areas, to gain a better understanding of the small elevation changes across natural marsh sites, especially in relation to changes in vegetation communities, changes from high to low marsh, and changes from marsh surface to marsh creeks and pools (collected 8-10 December 1998 in field, see Section II);

- measurement of slopes across the marsh surface and at the marsh edge (collected 8-10 December 1998 in field, see Section II);
- collection of vegetation quadrat data to test viability of similarity and diversity performance standards (collected 8-10 December 1998 in field, see Section II);
- aerial photographs that could be used for site design (obtained from ANWR 9 December 1998); and
- collection of data to increase knowledge of site foundation conditions and the quality of dredged material that is anticipated (to be collected as part of detailed design work).

Text Box 1. Funding Vehicles for Wetland Creation and Restoration Undertaken by the Corps

The Corps of Engineers has several vehicles for funding wetland creation and restoration projects. These vehicles are summarized here. Note that these funding vehicles are awarded on a nationally competitive basis. Official documentation should be consulted for detailed information.

- *Section 204—Implementing Ecosystem Restoration Projects in Connection with Dredging:* Section 204 funding is intended for projects that use dredged material to produce high value environmental outputs in a cost-effective manner, including projects that protect, restore, or create aquatic or wetland habitats in connection with dredging for construction, operation, or maintenance of a Federal project. No benefit-cost ratio is required, but the quantity and quality of the protection, restoration, and creation must be reconciled against costs associated with working beyond the dredging project's base plan. The base plan (the primary costs of dredging and associated activities) is fully funded from Federal sources, but costs above the base plan are funded via cost-sharing, with 75% of costs funded from Federal sources and 25% of costs funded from non-Federal sources (i.e., a local sponsor). Local sponsors must be legally-constituted public bodies.
- *Section 206—Aquatic Ecosystem Restoration:* Section 206 funding is intended to restore degraded ecosystem structure, function, and dynamic processes, usually through manipulation of hydrology. No relationship to a Corps project is required. No benefit-cost ratio is required, but the project's ability to improve the environment must be qualified and quantified. Total project costs are not to exceed $7.69 million, with no more than $5 million of these costs coming from Federal funding. Cost sharing allows for 65% Federal funding and 35% non-Federal funding. Work-in-kind can constitute part or all of the non-Federal 35% funding for the project, with the exception that work-in-kind is not applicable to the feasibility phase of the project. Local sponsors must be legally-constituted public bodies.
- *Section 1135—Project Modification for the Improvement of the Environment:* Section 1135 is intended for restoration of degraded ecosystem structure, function, and dynamic processes. Categories include modification of existing Corps projects, restoration where existing Corps projects contributed to environmental degradation, or restoration where construction or funding by the Corps or another Federal agency contributed to degradation of the environment. All Section 1135 restoration projects must have some connection to a Corps project. No benefit-cost ratio is required, but the project's ability to improve the environment must be qualified and quantified. Total project costs are not to exceed $6.6 million, with no more than $5 million of these costs coming from Federal funding. Cost sharing allows for 75% Federal funding and 25% non-Federal funding. Non-Federal sponsors may be public agencies, national non-profit groups, and private interests.

II. Investigations: Elevation, Vegetation, and Landscape-level Geomorphology

In this section, elevation, vegetation communities, and landscape-level geomorphology are each discussed. Information from this section is used in the Conceptual Design and Detailed Design sections of this report.

In wetland creation using dredged material, it is possible to design for and to some degree control three factors that will contribute to meeting goals, objectives, and performance standards established by the ICT. These factors are 1) elevation and topography, 2) vegetation community structure, and 3) site morphology. Appropriate elevations can be designed for and achieved through careful engineering, including application of appropriate models for consolidation of dredged material (which require detailed geotechnical data) as well as careful consideration of site area, existing bathymetry, and required volume of dredged material. The ICT determined that a performance standard for the objective "Develop habitat for fisheries" would require "Slopes and elevations within the range of those typical of natural marsh sites" in the project area (see Table 3). In addition, several other performance standards related to the objective "Support vegetation communities similar to those typical of Aransas National Wildlife Refuge" will require specific elevations. To identify appropriate target elevations and to quantify microtopographical variations in elevation, detailed survey work in natural marshes of the project area as well as a review of available survey data were required. Throughout this report, the project area includes Welder Flat and Aransas National Wildlife Refuge marshes.

While vegetation communities will evolve over time to reflect prevailing environmental (physical and biological) conditions, initial planting of appropriate vegetation assemblages can prevent or at least delay problems with establishment of nuisance plant species or dominance by one or a small number of species. Also, planting can contribute to accelerated consolidation of dredged material through evapotranspiration, protection from erosion by development of a root mat, rapid development of habitat structure to support birds and other wildlife, and potentially improved wetland functioning in terms of biogeochemical cycling and nutrient dynamics. One of the ICT's stated objectives for the wetland creation aspects of the 50-year DMMP was "Support of vegetation communities similar to those typical of Aransas National Wildlife Refuge." To understand vegetation community structure at the level required for design of appropriate planting schemes, vegetation survey work, linked to microtopographical elevation survey work, was required.

In a created wetland, appropriate use of structures, strategic placement of dredge discharge pipes, and post-consolidation contouring can lead to the desired landscape-level geomorphology. The ICT determined that performance standards for the objective "Develop habitat for fisheries" would require 1) "Edge:area ratio equal to or greater than the median edge:area ratios of natural marsh sites at Aransas National Wildlife Refuge," and 2) "Area of open water habitat with connection to tidal flushing is equal to or greater than median areas of open water habitat with connection to tidal flushing in natural marsh sites at Aransas National Wildlife Refuge." Both of these performance standards require consideration of landscape-level morphology of natural marshes in the project area. Note that here, and throughout this report, the term "landscape-level geomorphology" is used to describe the geomorphology that can be determined from aerial photographs, and does not include consideration of elevation and slopes. Elevation and slopes are considered separately from landscape-level geomorphology. High resolution, large scale aerial photographs, such as Digital Orthophoto Quarter Quadrangles (DOQQ), are required to better understand landscape-level morphology of sites. For this report, unrectified aerial photographs with an approximate scale of 1:6,000 (1 inch = 500 feet) were obtained from ANWR.

Elevation

Detailed survey work was undertaken at eleven sites in the project area (i.e., Welder Flat and Aransas National Wildlife Refuge marshes) on 8-10 December 1998. Approximate locations of sites are identified in Figures 3a (Welder Flat sites) and 3b (Aransas National Wildlife Refuge sites). Site choice was limited by the presence of Whooping Cranes.

Personnel from the Army Corps of Engineers Galveston District and the US Army Engineer Research and Development Center, Waterways Experiment Station, conducted surveys using a Real Time Kinematic On-The-Fly (RTKOTF) Global Position System (GPS) (Trimble 4000 SSI) (Figure 4). Base stations were established near the boathouse next to the Welder Flat channel (sometimes called Cliburn's Channel) and near the boat landing at Aransas National Wildlife Refuge. Base station coordinates were 2757027.887 (Easting) / 188731.242 (Northing) / 8.010 (elevation) for the Welder Flat sites, at a point permanently marked by a disc set in concrete near the boathouse. Base station coordinates were 2708880.425 (Easting) / 151163.915 (Northing) / 7.808 (elevation) for the Aransas National Wildlife Refuge sites, at a point permanently marked by a bolt near the boat landing.

Survey data were collected along transects and in grids (comprised of multiple parallel transects spaced at 1-m intervals), with coordinates collected at roughly 1-m to 2-m intervals along transects. The objective of surveying was to assess microtopography in a way that could provide insight for wetland creation design. As such, sites were chosen subjectively to cover a variety of situations within the constraints of avoiding wintering Whooping Cranes. Sites with different vegetation communities located at different distances from the Intracoastal Waterway, and with different densities of ponds and depressions, were included. One area selected from aerial photographs because of its high edge:area ratio, to the

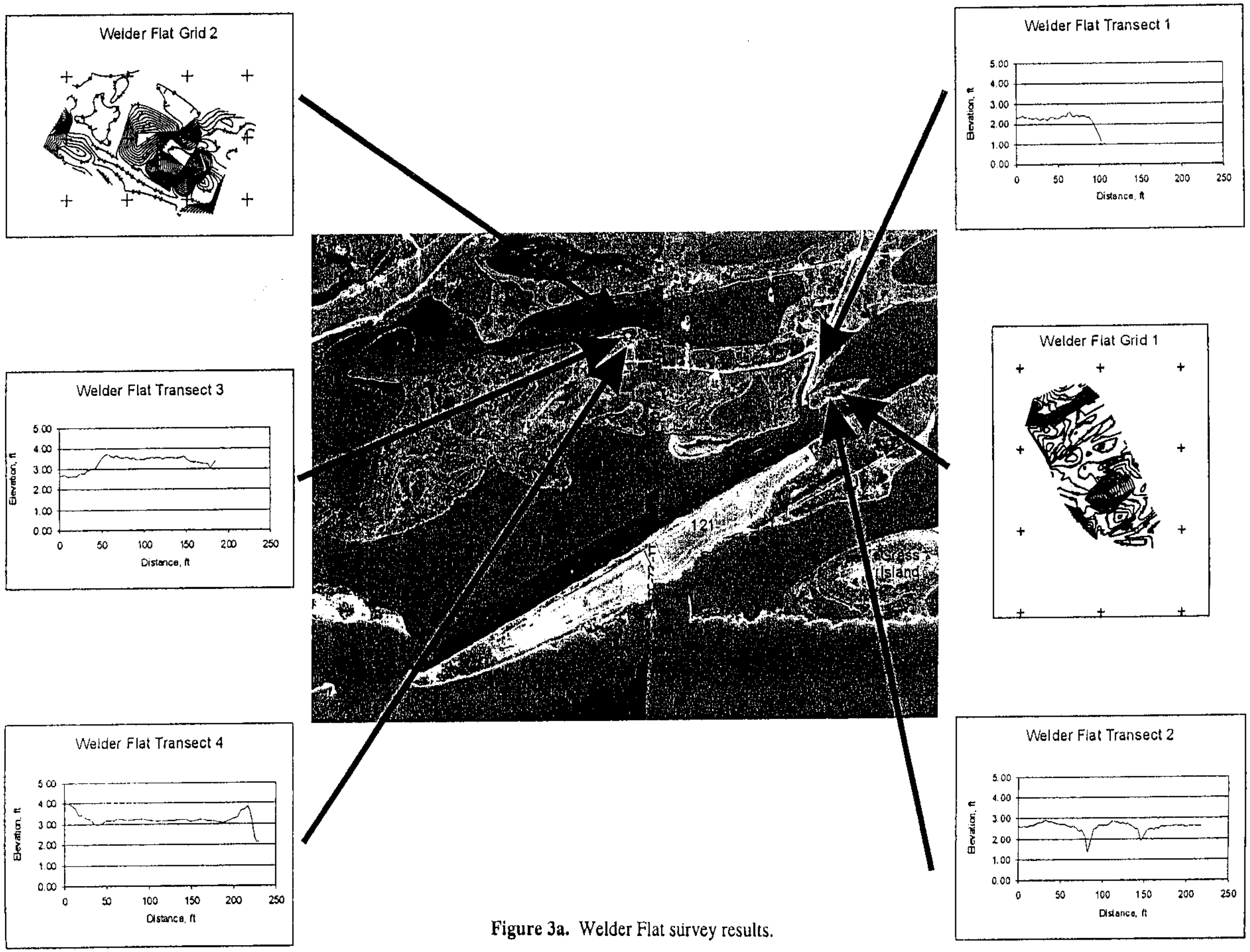


Figure 3a. Welder Flat survey results.

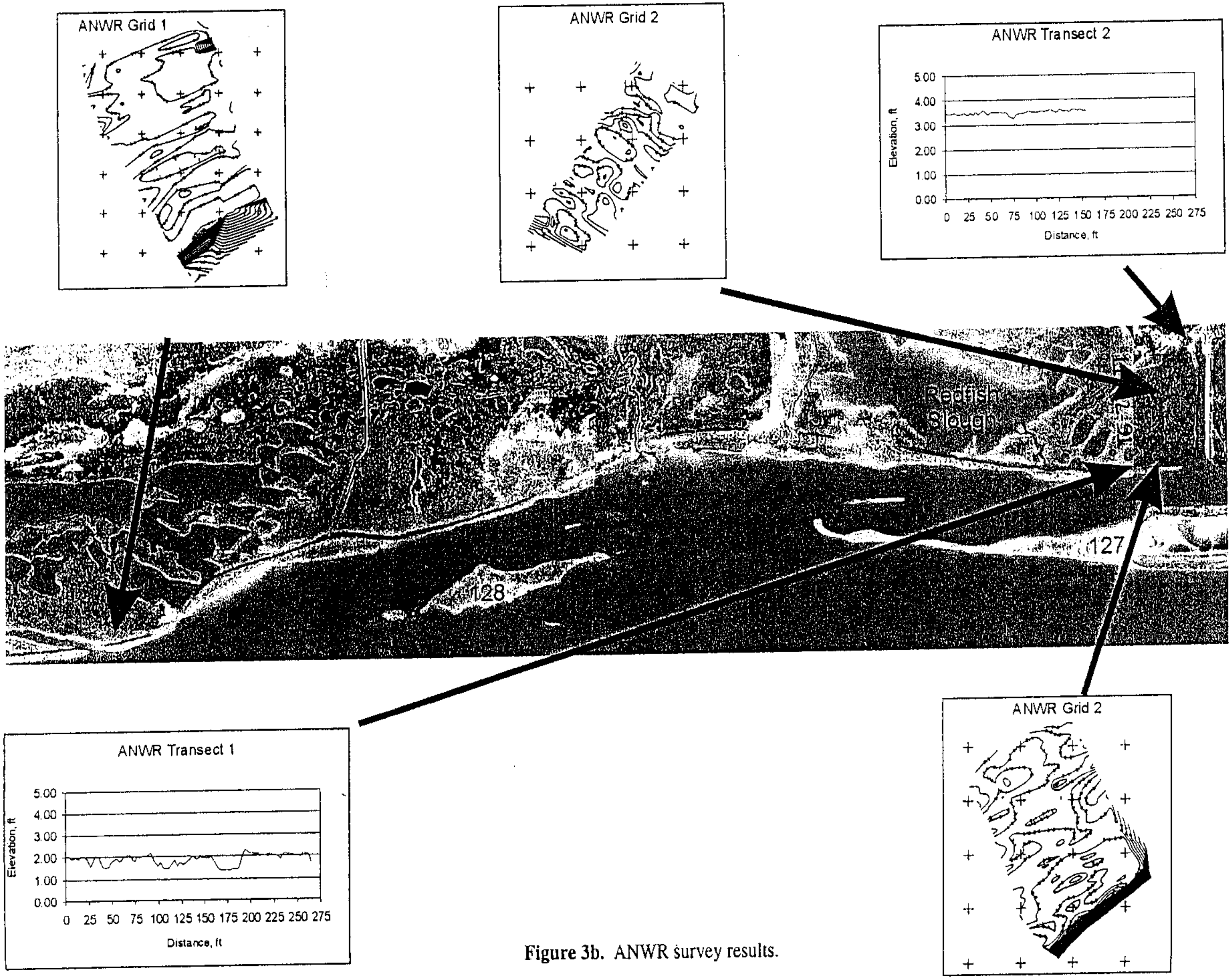


Figure 3b. ANWR survey results.

northeast of the Aransas National Wildlife Refuge boat landing, could not be surveyed because Whooping Cranes were present.

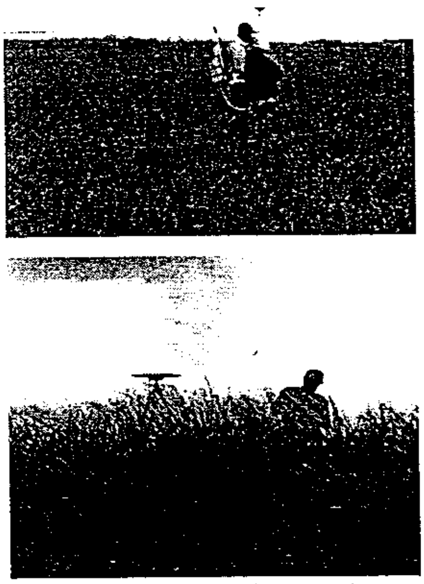


Figure 4. In bottom photograph, Cleo Dow establishes RTKOTF surveying base station at Aransas National Wildlife Refuge; in top photograph, Cleo Dow and Gail Stewart (right) collect survey data.

Survey data had a nominal precision of less than 1 inch. However, the sediments at many of the survey points were very soft, so surveyors had to subjectively identify a "true ground level," which introduced an unmeasured error in the vertical dimension (elevation) that probably exceeded the nominal precision of survey data in the vertical dimension; this error probably varied from 1-3 inches. A total of 1,264 points were surveyed. Elevations, not including those of base station points, ranged from 0.174 ft MLT to 3.97 ft MLT across all sites. Lowest elevations were from points at the edge of Intracoastal Waterway, in unvegetated open water. Highest elevations were from points near the Aransas National Wildlife Refuge boat ramp, in areas generally dominated by *Spartina patens.*

Tide ranges, based on data from the Copano Bay water level gauge (gauge maintained by the Texas Coastal and Ocean Observation Network) are plotted in Figure 5, and the location of the gauge is shown in Figure 6 (28.1145^0 N, 97.0242^0 W). Data suggest that the lowest elevations surveyed on the edge of the Intracoastal Waterway, at less than 1 ft MLT, are flooded at all times. Highest elevations, at greater than 3.5 ft MLT, would only be flooded by tidal water during extreme high tide events, such as occurred in late 1996 and late 1997 (Figure 5).

Elevations for individual transects and grids are summarized in Table 4 and plotted in Figures 3a and 3b. Within individual sites, elevations could vary by up to 2.4 feet. Darnell reported slopes of 0.5% in unvegetated habitat of Aransas National Wildlife Refuge marshes and 0.3% for areas with emergent vegetation in Aransas National Wildlife Refuge marshes. However, it should be noted that Darnell's surveys relied on a small number of survey points to compute slope and variability related to microtopographic relief may influence reported scores.

Differences in elevation between the vegetated areas surrounding ponds or flooded depressions and the unvegetated bottoms of ponds or depressions were typically less than 6 inches. Differences between the vegetated areas surrounding tidal channels and the unvegetated tidal channel bottoms were typically less than 9 inches. These differences are about 3 inches greater than differences reported by Darnell et al. (1997) for Aransas National Wildlife Refuge, based on interpretation of Darnell et al.'s Figure 7 (reproduced in this report as Figure 7).

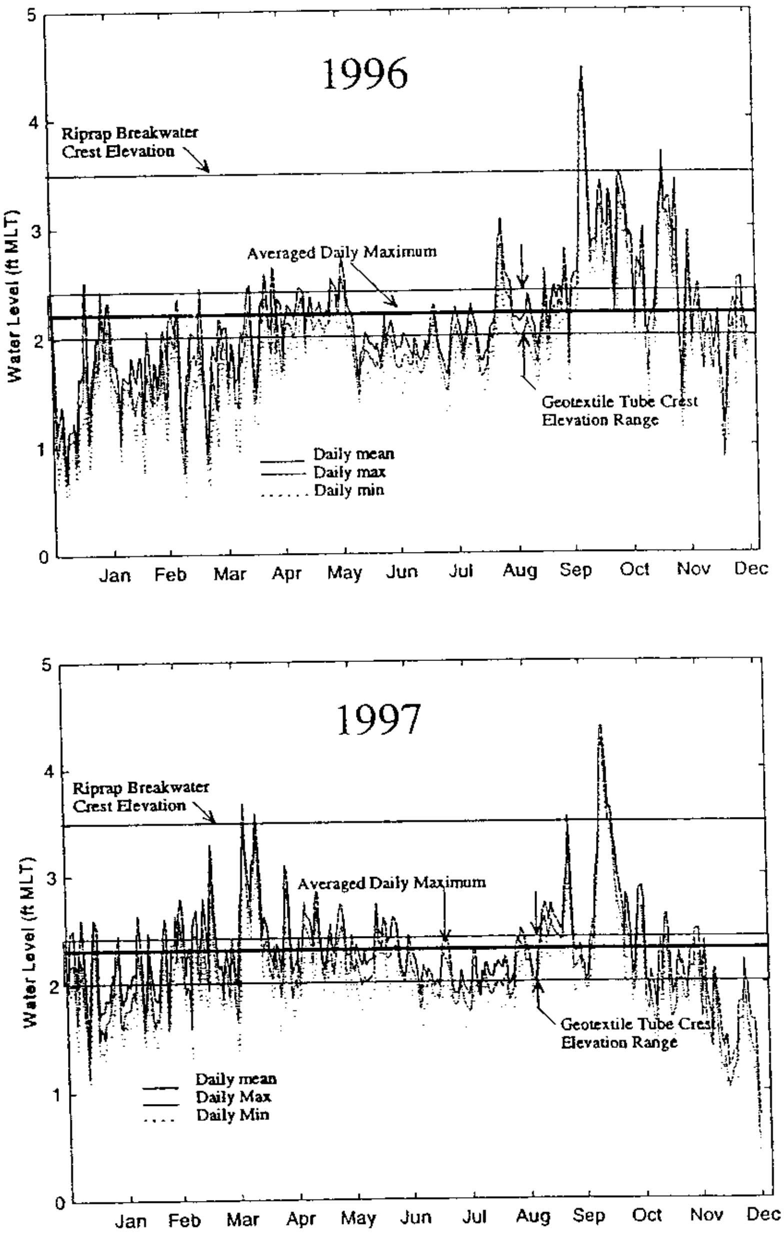


Figure 5. Water levels at study sites in 1996 and 1997, along with elevations of existing structures protecting PA 127a and 128. The highest survey elevations on natural marshes were 3.97 ft, while the lowest were 0.174 ft. Highest survey elevations were rarely inundated during 1996/97, while lowest survey elevations were almost always innundated. Lowest survey elevations were from unvegetated open water at the edge of the Intracoastal Waterway. Lowest vegetated elevations were typically around 1.7 feet. Data from Copano Bay Tide Gauge.

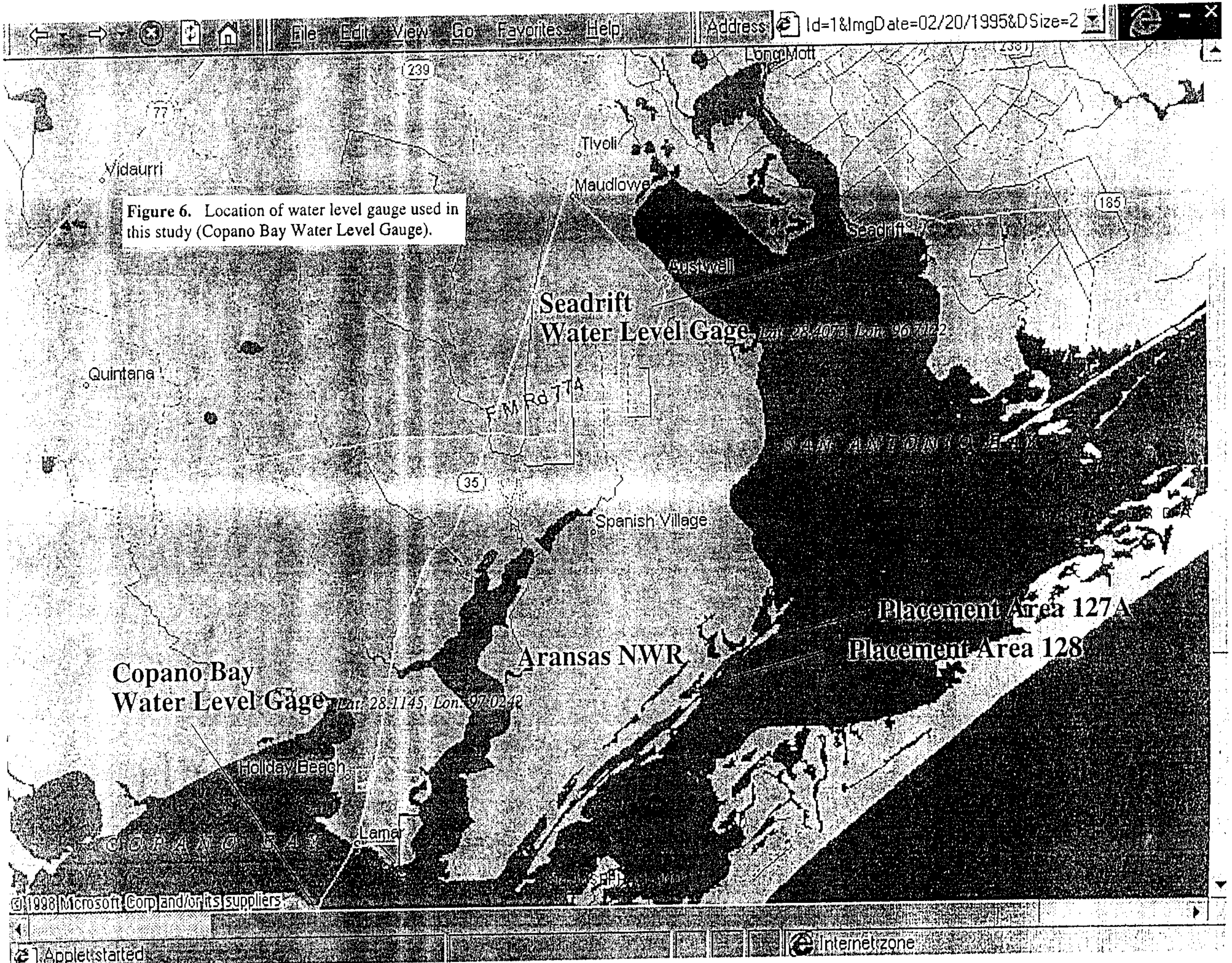


Figure 6. Location of water level gauge used in this study (Copano Bay Water Level Gauge).

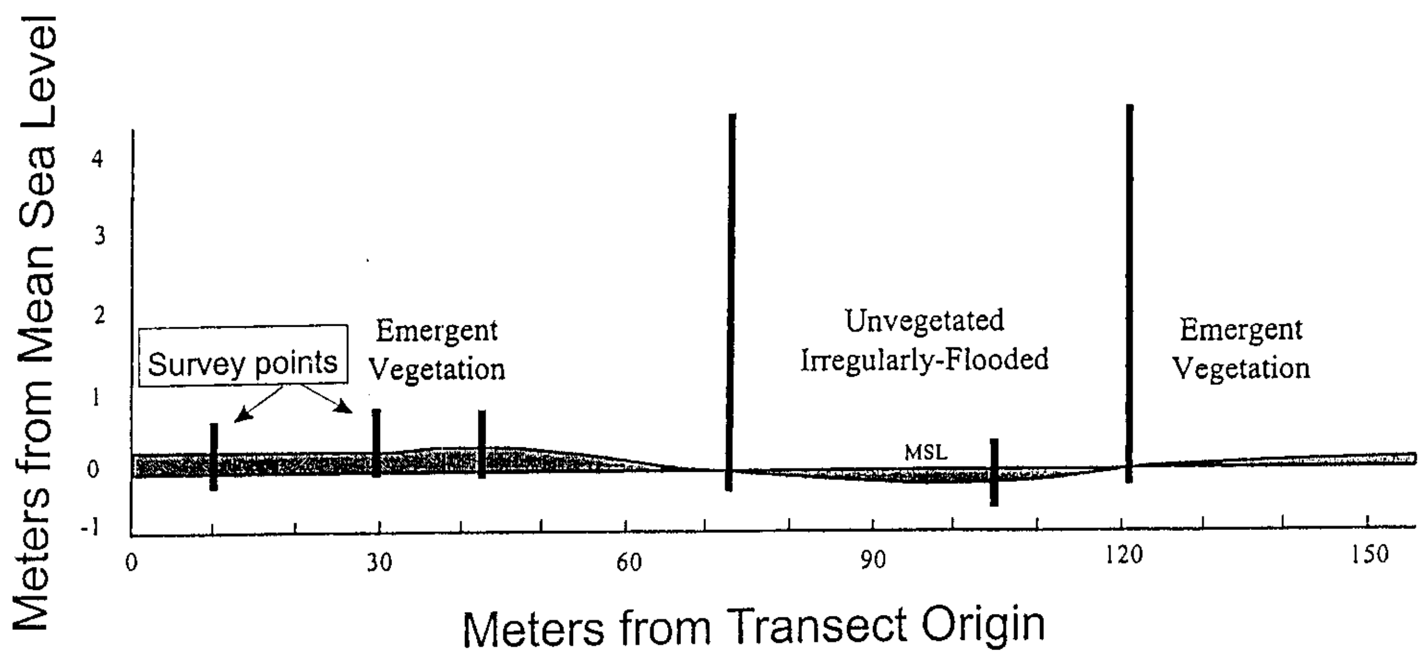


Figure 7. Contour profile, adapted from Figure 7 in Darnell et al. 1997. Note that the coutour profile is based against mean sea level, rather than mean low tide, and that the profile is based on a limited number of survey points.

Vegetation

Areal cover by plant species was estimated in 1-m^2 quadrats at each site where elevation surveys were conducted, concurrent with elevation surveys on 8-10 December 1998 (Figure 8). Quadrats were placed on the marsh surface at irregular intervals within surveying grids and transects. Because vegetation estimates required more time per quadrat than was required to measure surveying coordinates, there are fewer vegetation quadrats than elevation data points; in total, areal cover was estimated in 306 quadrats. Tables 5 and 6 describe vegetation from Welder Flat and Aransas National Wildlife Refuge sites, respectively. Figures 9 and 10 summarize percent contributions from the eight most abundant plant species and bare ground for each site at Welder Flat and Aransas National Wildlife Refuge sites, respectively.

At most sites, bare ground was the most abundant cover class. Although salt marsh vegetation in the project area generally persists through winter months, senescence and partial winter die-back (sampling was undertaken on 8-10 December 1998) may have resulted in larger percentages of bare ground than would be found during warmer months. Fifteen plant species were found in quadrats (see Tables 4 and 5), but only eight species occurred frequently enough to be considered important contributors to plant community structure at any of the sites: *Batis maritima*, *Borrichia frutescens*, *Distichlis spicata*, *Lycium carolinanum*, *Monanthochloe littoralis*, *Salicornia virginica*, *Spartina alterniflora*, and *Spartina spartinae*.

Figures 9 and 10, which summarize data on the nine most abundant cover types (bare ground and eight plant species) found in quadrats, suggest the variability between sites. Even sites that are geographically close and have similar elevations may have very different plant communities. For example, in Welder Flat Grid 1, *Batis maritima* was the most abundant vegetation cover class (i.e., the most abundant cover class not including bare ground), with *Distichlis spicata* as the second most abundant cover class. Nearby, at Welder Flat Transect 2, *Batis maritima* was considerably less abundant, and *Distichlis spicata* covered less than 1% of quadrat area. Elevations at the two sites were similar: elevations for Welder Flat Grid 1 ranged from 1.99-2.61 ft MLT, with a mean of 2.46 ft MLT, while elevations at Welder Flat Transect 2 ranged from 1.89-2.84 ft MLT, with a mean of 2.58 ft MLT (for elevations taken at plant quadrats, as per Table 5). Thus, differences in elevation are small and may not explain differences in vegetation. Similarly, at Aransas National Wildlife Refuge Transect 1, *Distichlis spicata* and *Batis maritima* were the most abundant vegetation cover classes, but at nearby Aransas National Wildlife Refuge Grid 3 *Borrichia frutescens* was the most abundant vegetation cover class, with *Batis maritima* covering less than 6% of quadrat area and *Distichlis spicata* covering less than 3% of quadrat area. Again, elevations at the two sites were similar: elevations at Aransas National Wildlife Refuge Transect 1 ranged from 1.71-2.22 ft MLT, with a mean of 1.99 ft MLT, while elevations at Aransas National Wildlife Refuge Grid 3 ranged from 1.94-2.45 ft MLT, with a mean of 2.21 ft MLT (for elevations taken at plant quadrats, as per Table 6). Just as in the previous example, differences in elevation may not explain differences in plant

Table 4. Elevation ranges for surveyed sites, in feet above MLT.

Welder Flat	Lowest elevation	Highest elevation
Transect 1	1.468	2.616
Transect 2	1.344	2.897
Transect 3	2.621	3.716
Transect 4	2.086	3.970
Grid 1	1.296	2.644
Grid 2	1.824	3.316
Aransas National Wildlife Refuge		
Transect 1	1.337	2.265
Transect 2	3.253	3.621
Grid 1	1.153	2.933
Grid 2	1.778	2.457
Grid 3	0.174	2.582

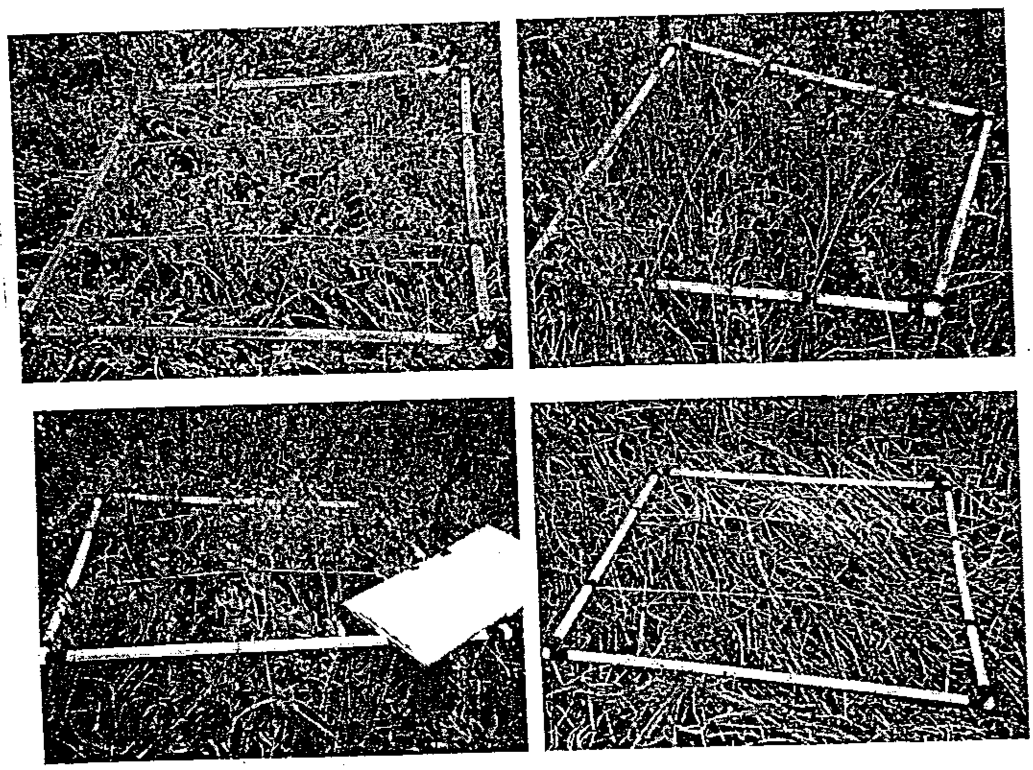


Figure 8. Plant quadrats (1 m^2) were used to assess vegetation communities at sites. Areal cover for each species and for bare ground was visually estimated for each quadrat.

Table 5. Summary of vegetation grids and transects for Welder Flat sites. Values are mean percent cover values from 1-m^2 quadrats. "P" indicates species present at less than 1% mean cover. In general, variances (not listed) were much greater than means, reflecting a high degree of patchiness (i.e., an aggregated dispersion pattern in plant distributions) within sites.

Scientific name	Common name[1]	Grid 1	Grid 2	Transect 1	Transect 2	Transect 3	Transect 4
bare ground	—	41.2	39.6	29.0	35.5	45.3	41.8
Aster tenuifolius	(Perrenial salt marsh aster)	0	0	P	P	0	0
Batis maritima	Saltwort	39.6	27.0	9.5	16.8	19.1	6.2
Borrichia frutescens	Sea-oxeye (Sea-oxeye daisy)	1.5	1.5	6.0	2.8	1.3	3.3
Cuscuta sp.	Dodder	0	0	0	0	0	P
Distichlis spicata	Spike grass (salt grass)	11.0	1.9	33.6	P	P	6.9
Lycium carolinianum	Christmas berry (wolf berry)	1.1	1.9	P	1.0	1.6	P
Monanthochloe littoralis	Key grass	6.7	9.4	P	13.5	1.6	4.4
Salicornia bigelovii	Annual glasswort	0	0	0	0	P	0
Salicornia virginica	Perennial glasswort	P	2.2	16.7	20.6	31.6	6.8
Spartina alterniflora	smooth cordgrass	0	18.1	6.1	10.5	1.3	30.0
Mean (and range) of elevation (in ft MLT)		2.46 (1.99-2.61)	2.25 (1.95-3.32)	2.24 (1.47-2.38)	2.58 (1.89-2.84)	3.42 (3.00-3.64)	3.27 (2.26-3.97)
Number of quadrats		46	40	10	20	16	17

[1]As per Godfrey and Wooten 1981; parenthetical common names are from local usage.

Table 6. Summary of vegetation grids and transects for Aransas National Wildlife Refuge sites. Values are mean percent cover values from 1-m^2 quadrats. "P" indicates species present at less than 1% mean cover. In general, variances (not listed) were much greater than means, reflecting a high degree of patchiness (i.e., an aggregated dispersion pattern) in plant distributions within sites. Unknowns 1-3 were small forbs without flowers that could not be identified based on available plant material.

Scientific name	Common name[1]	Grid 1	Grid 2	Grid 3	Transect 1	Transect 2
bare ground	—	47.1	32.9	41.7	51.5	17.7
Aster tenuifolius	Perennial salt marsh aster)	0	0	P	0	0
Batis maritima	Saltwort	15.9	28.2	5.6	19.5	P
Borrichia frutescens	Sea-oxeye (Sea-oxeye daisy)	25.8	1.4	48.0	3.1	7.4
Cuscuta sp.	Dodder	P	0	P	0	0
Distichlis spicata	Spike grass (salt grass)	4.9	8.5	2.8	27.2	0
Lycium carolinianum	Christmas berry (wolf berry)	3.5	2.7	P	P	P
Monanthochloe littoralis	Key grass	3.6	28.2	P	0	51.0
Salicornia bigelovii	Annual glasswort	0	P	0	0	0
Salicornia virginica	Perennial glasswort	P	P	2.8	P	5.5
Scirpus c.a. *americanus*	Bulrush	0	0	P	0	0
Spartina spartinae	Gulf cordgrass	0	0	0	0	20
Unknown 1		0	0	0	0	P
Unknown 2		0	0	0	0	P
Unknown 3		0	0	0	0	P
Mean (and range) of elevation (ft MLT)		2.60 (2.41-2.83)	2.12 (1.87-2.44)	2.21 (1.94-2.45)	1.99 (1.71-2.22)	3.49 (3.25-3.60)
Number of quadrats		40[2]	41	46	20	10

[1]As per Godfrey and Wooten 1981; parenthetical common names are from local usage.
[2]Elevation data available from only 21 of 40 vegetation quadrats.

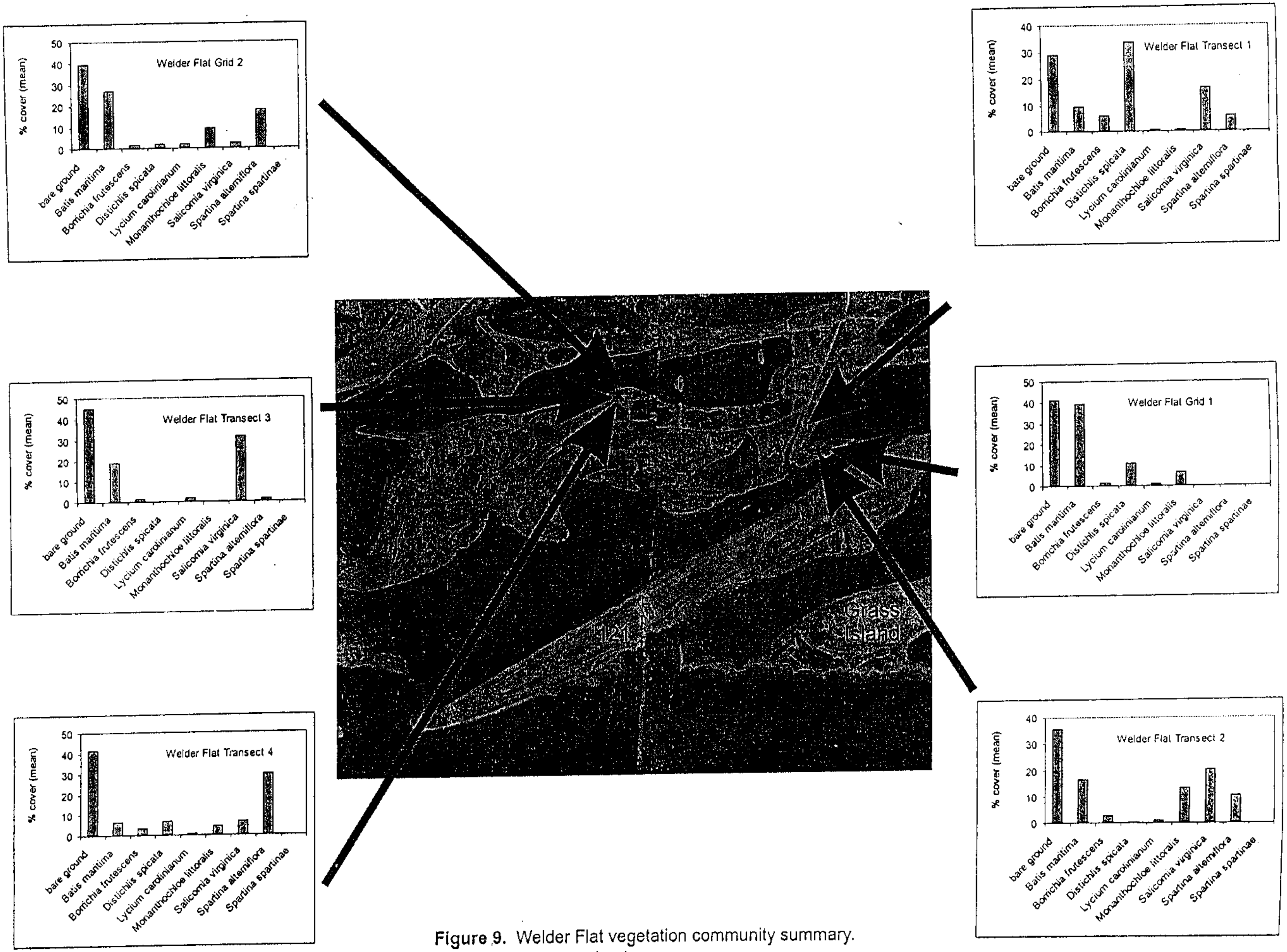


Figure 9. Welder Flat vegetation community summary. Locations are approximate.

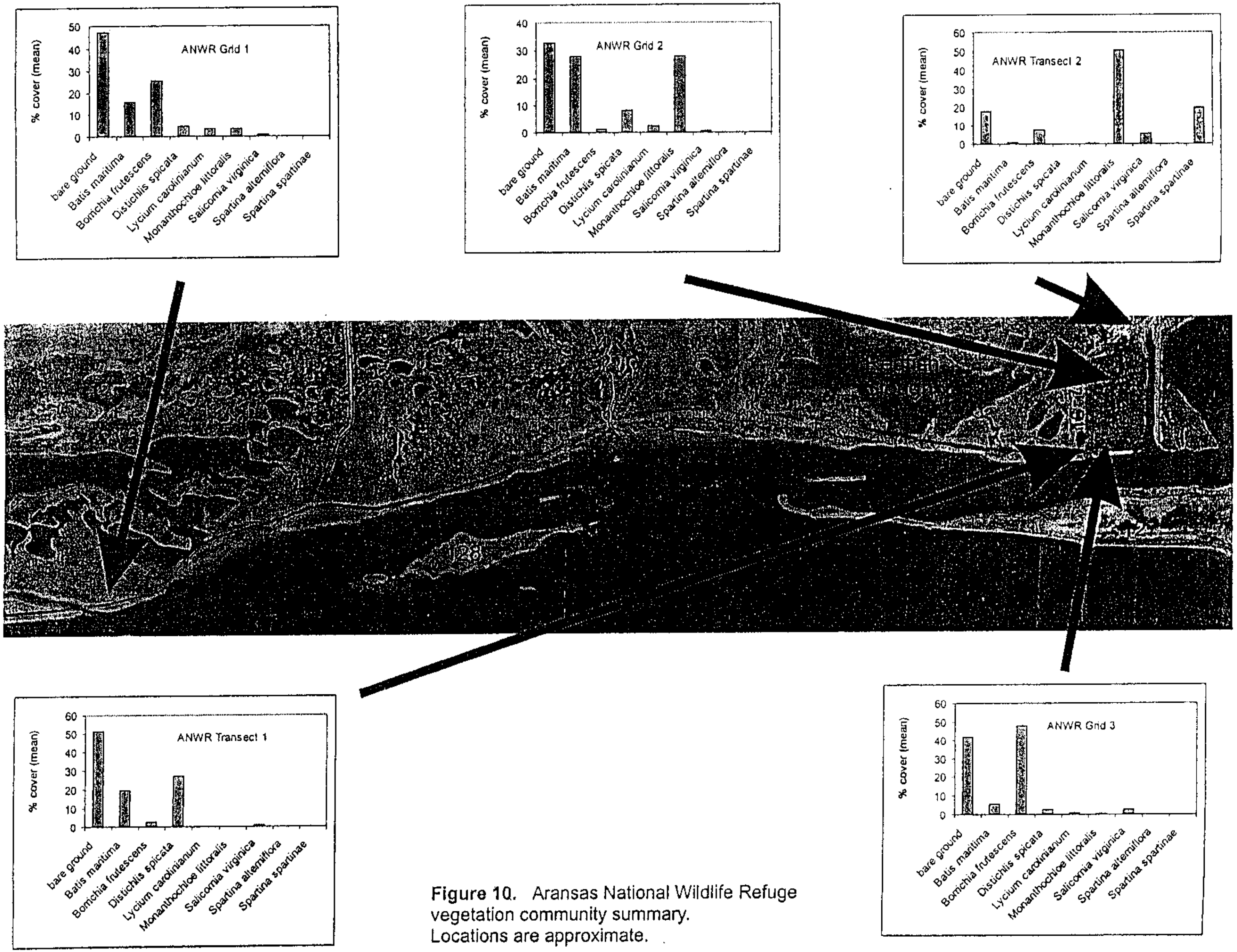


Figure 10. Aransas National Wildlife Refuge vegetation community summary. Locations are approximate.

communities. The point of this discussion is to suggest that within the marshes, differences in vegetation community structure may be driven by stochastic events that would be difficult or impossible to duplicate or predict. For example, factors such as grazing pressure and seed set may drive one part of the marsh toward dominance by *Borrichia frutescens* and another toward dominance by *Batis maritima*. The end result is a vegetation mosaic without clear zonation.

Cuscuta sp., a parasitic plant without chlorophyll that frequently occurs in salt marshes, was present in several quadrats. *Scirpus americanus*, a plant typically associated with brackish marshes or salt marshes with freshwater input via creeks or rain, was scattered through Aransas National Wildlife Refuge Grid 3, apparently growing from seed rather than via vegetative spread (based on the scattered occurrence of plants). Quadrats with *Scirpus americanus* had elevations of 2.0 to 2.3 ft MLT, and would therefore be frequently inundated by tidal flooding (see Figure 5). Rainwater may depress salinities sufficiently to allow germination and survival of *Scirpus americanus*, but the species may disappear during periods of drought. This is one example of a form of interannual variability in plant community structure that may occur in the project area. Both *Cuscuta* sp. and *Scirpus americanus* are two examples of species seldom seen in quadrats but known to occur in salt marshes.

Correlation analysis was used to further assess the relationship between various cover types (i.e., bare ground and plant species) and between cover types and elevation (Table 7). Of sixty-six relationships assessed, twenty-four were significant at the $p < 0.05$ level; of these significant relationships, only the negative relationship between *Monanthochloe littoralis* and bare ground had a correlation coefficient greater than $|0.5|$. Where *Monanthochloe littoralis* occurred, it frequently formed a dense ground cover that resulted in low percentages of bare ground. Correlation analysis did not suggest that any of the species considered had a mutually exclusive relationship; that is, the presence of one species within a 1-m^2 quadrat did not consistently mean that any other species would be absent. The weakness of correlations, both negative and positive, reinforces the suggestion that plant communities at these sites are best thought of as mosaic communities, rather than as communities with clear zonation (see, for example, Zedler et al. 1995). However, this is a small data set for assessment of infrequently occurring species and would not have allowed detection of relationships for some species. For example, *Spartina alterniflora* and *Spartina spartinae* never occurred in the same quadrat, but what would appear to be a strong negative relationship between the two species (probably related to elevation) was obscured by the large number of quadrats with neither species, and the relationship was not statistically significant.

Significant relationships between elevation and common cover types were plotted (Figure 11). Plots illustrate the weakness of relationships and serve as a reminder that significant relationships may not "explain" plant distributions or offer predictability useful for site design. For example, there is a significant relationship between bare ground areal cover and elevation, but the r^2 value suggests that elevation only explains 7% of the variability in the areal cover by bare ground. The scatter of points in Figure

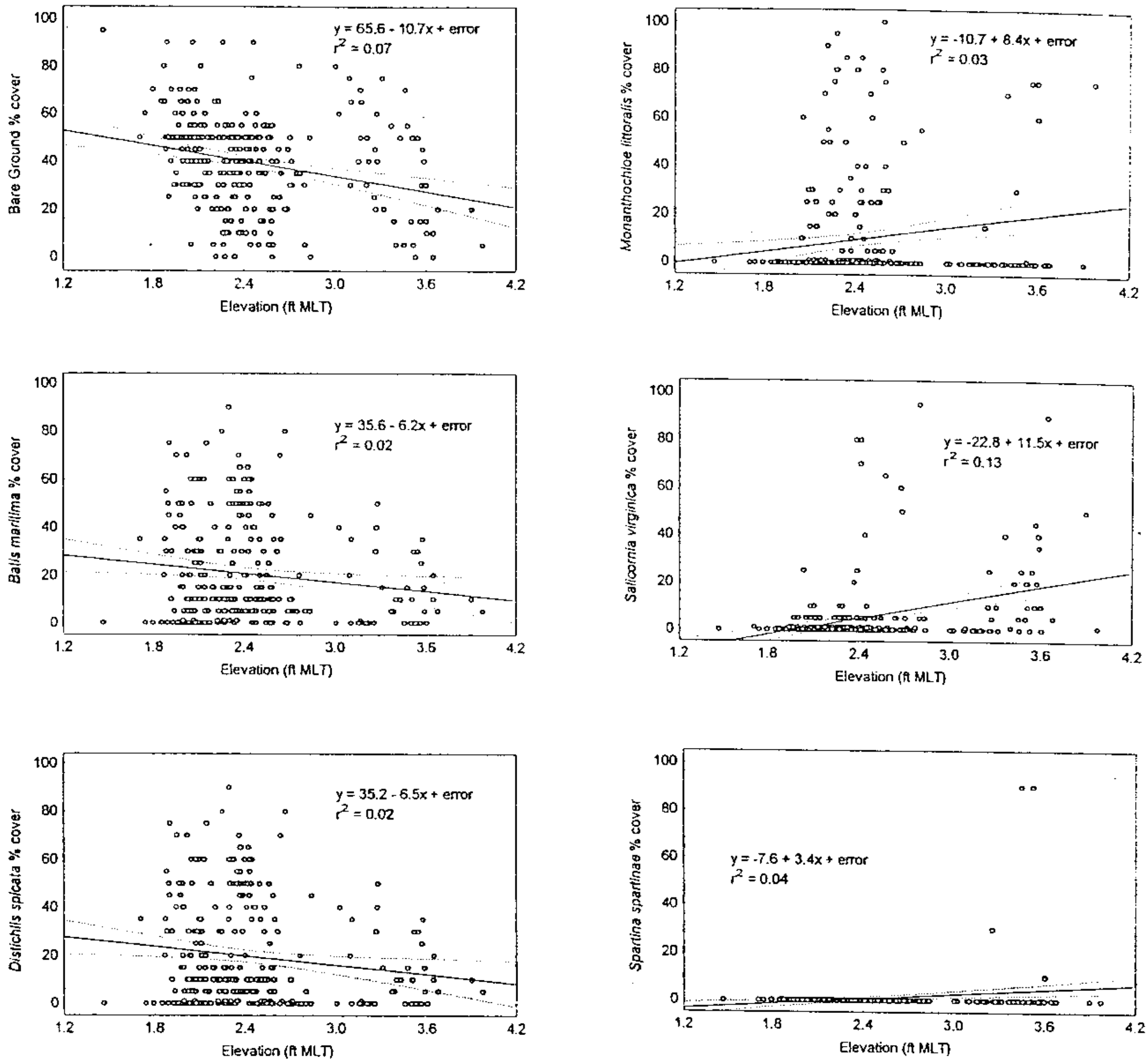


Figure 11. Relationships between elevations and areal cover by cover types (bare ground and plant species) significantly related to elevation. Low r^2 values suggest that the relationships between elevation and cover type, while statistically significant, is weak.

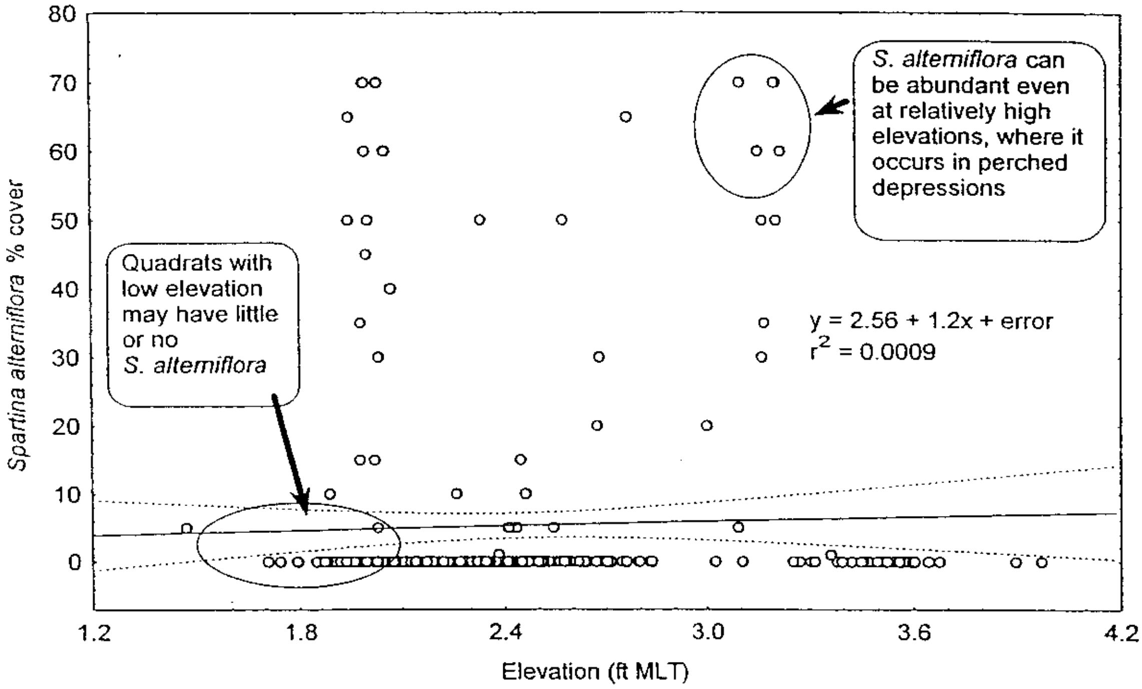


Figure 12. Although *Spartina alterniflora* is typically expected to grow at the lowest vegetated elevations within a marsh complex, there is no clear relationship between *Spartina alterniflora* and elevation for the marshes of the project area. The plot shown here illustrates this point. Note that the relationship depicted by the regression line is not significant at the $p < 0.05$ level (that is, there is no evidence to suggest that elevation, within the range of elevations examined, can predict *Spartina alterniflora* abundance). Circled and annotated data points reinforce the inconsistency of the paradigm linking low elevations with *Spartina alterniflora* abundance.

11 also shows the variability in areal cover of bare ground that is unrelated to elevation. The *Salicornia virginica* plot shows the strongest relationship between a cover type and elevation, but even this relationship only explains about 13% of the variability in the data, and, again, the scatter of data points illustrates the weakness of this relationship. For other cover types with areal cover significantly related to elevation, elevation cannot explain (or predict) more than 7% of the variability. In short, within the range of elevations that occurred on study plots, a knowledge of elevation is of little value in predicting or explaining cover types.

This conclusion is difficult to reconcile with paradigms of marsh ecology that suggest a strong relationship between elevation and plant community structure. For example, *Spartina alterniflora* typically would be expected at the lowest elevations, followed by a mixture of species such as *Distichlis spicata*, *Borrichia frutescens*, *Monanthochloe littoralis*, and *Lycium carolinanum* at slightly higher elevations, and *Spartina spartinae* at the highest elevations. However, even a plot of *Spartina alterniflora* against elevation fails to show a clear relationship (Figure 12), and in fact the relationship that is present is not significant at the $p<0.05$ level.

Failure to find a strong relationship between elevation and plant community structure in the data set collected at the project site could be interpreted in several ways:

1. Elevation and/or plant data are not accurate.
2. The data set is too small to define relationships between elevation and plant community structure.
3. The paradigm linking elevation and marsh community structure is wrong, or does not apply at the project site.
4. The expected relationship between elevation and plant community structure is weakened when data from all sites are combined because similar elevations at different sites experience different inundation frequencies and duration.

Each of these possibilities is discussed below.

Elevation and/or plant data are not accurate. There is no *a priori* reason to suspect that elevation data are inaccurate. Elevation data were collected using standard methods, state-of-the-art equipment, and with the assistance of an experienced surveyor (Cleo Dow of the Army Corps of Engineers Galveston District). Similarly, vegetation data were collected by an experienced wetland ecologist (Bill Streever of Waterways Experiment Station) using standard quadrat methods. Although time constraints prevented assessment of quadrat measurement precision (that is, consistency of areal cover estimates) at the project site, past precision assessments of data collected using quadrats at other locations suggests that precision was well within practicable limits expected with this method (see, for example, Streever and Genders 1997). In short, data inaccuracy is not a reasonable explanation for the weakness in the relationship between elevation and vegetation communities.

The data set is too small to define relationships between elevation and plant community structure. Arguably, the data set may be too small to identify statistically significant relationships between vegetation and elevation. It is a basic premise of research design that increased sampling effort leads to increased statistical power, or the ability to detect significant relationships (in this case, relationships where $p < 0.05$ for the null hypothesis stating that the slope of the regression line is equal to 0) (see, for example, Streever and Portier 1994). In fact, a reasonably large number of samples were collected in this study ($n = 306$ for the total number of plant quadrats). Because all samples came from only eleven sites, each quadrat was not independent, and so some of the information used in the analyzes was redundant, or was "pseudoreplicated data," in the sense of Hurlbert (1984). Because one objective of field work was to identify microtopographic characteristics of the project site, true replication (i.e., independence of sampling) was sacrificed in favor of an approach relying on grids and transects; true replication would have required quadrat sampling of widely spaced, randomly selected points. However, for six of the most common species at the project site, the correlation between cover type and elevation was significant, and increased sample size would not have changed this outcome (except in the sense of making significant p values even smaller). In fact, the weakness of the relationships between cover types and elevation was not so much one of inability to find significance (i.e., low power) as it was one of low correlation coefficients for relationships that were statistically significant. That is, elevation was significantly correlated with vegetation cover but could only account for, or "predict," a small amount of the variability in cover type data. Increasing sample size would not have increased the ability of elevation to account for variability in cover type data. Scatter plots in Figures 11 and 12 illustrates this concept: more data points would have been scattered across the plots, just as existing points are scattered across the plots. In short, the data set is large enough to identify any ecologically important relationships between cover types and elevation, despite shortcomings related to one form of pseudoreplication.

The paradigm linking elevation and marsh community structure is wrong, or does not apply at the project site. It is possible, although unlikely, that the ecological paradigm linking elevation and plant community structure is wrong, although given the scrutiny that this paradigm has attracted over the past 20 to 30 years, this possibility is unlikely. The possibility that the paradigm does not apply at the project site is somewhat more likely. Most research supporting the paradigm relating elevation to plant community structure was undertaken in areas such as Sapelo Island, Georgia, where tide ranges exceed several feet and where variability in elevation is greater than that found at the project site. However, in the context of created wetland design, there is little conceivable benefit to abandoning this paradigm, and in any case the data set collected to support created wetland design would not, on its own, justify abandoning this well-established paradigm. Nevertheless, it seems likely that stochastic factors, such as grazing pressure and seed-set, may override the importance of elevation in controlling plant community structure, especially when elevation and tide ranges are narrow, as is the case in these sites. Even in sites where elevation and tide ranges are much larger than those of the project site, and where elevation is a good predictor of plant community structure, other factors, such as grazing pressure and interspecific plant competition (for example, see Bertness and Ellison 1987; Bertness et al. 1987; Taylor and Grace 1995; and Streever and Genders 1997), are known to play a role in zonation. That is, plant community zonation is not a direct response to elevation that excludes all other influences, even on sites with large tide and elevation ranges. In short, the paradigm linking elevation and plant community structure is not well supported by the data presented in this report, and elevation may have no more than a weak link to plant community structure.

The expected relationship between elevation and plant community structure is weakened when data from all sites are combined because similar elevations at different sites experience different inundation frequencies and duration. Elevation typically controls frequency and duration of inundation in tidal wetlands. Plants that are at higher elevations will generally be inundated less often, and for less time, then sites at lower elevations. The paradigm linking elevation and plant community structure uses elevation as a surrogate for inundation frequency and duration. Also, salinity and redox conditions related to duration and frequency of inundation are known to influence plant growth. Because elevation is typically linked to inundation, elevation can be measured and related to plant community structure in many instances. The weakness in the relationship between elevation and plant community structure for the data reported here may in fact reflect a poor relationship between elevation on the one hand and frequency and duration of flooding on the other hand for the surveyed sites. That is, a point at an elevation of 3 ft MLT, for example, at Aransas National Wildlife Refuge Grid 1 may not be inundated as frequently or as long as a point at an elevation of 3 ft MLT at Welder Flat Grid 2. As tides move past obstructions and through channels, tidal ranges can be attenuated. Alternatively, certain land forms can accentuate tidal ranges by funneling large volumes of water into small areas, as occurs, for example, along the Georgia Bight and the Bay of Fundy on the North American east coast. Aspect of openings to coves or inlets and associated fetch may also influence inundation duration and frequency in areas where wind plays a significant role in driving water levels. Areas at high elevations with depressions or areas blocked by wave berms (areas where wave-deposited sediment forms slightly higher ground at the interface between the Intracoastal Waterway and the marsh) may remain inundated longer than well-drained areas. Inundation frequency and duration can be further complicated by freshwater inputs.

Direct measurement of inundation duration and frequency is time consuming and expensive; it requires use of stage recorders deployed for long periods at many locations. Because direct measurement is usually impracticable, measurement of elevation is used as a surrogate. If inundation duration and frequency differs between sites for a given elevation, relationships between plant community structure and elevation should be stronger for data collected at individual sites (given the same sampling effort) than for data collected at multiple sites. With this in mind, relationships between elevation, bare ground, and areal cover for common plant species were examined using correlation analysis for two sites, the Welder Flat Grid 2 site and the ANWR Grid 2 site; that is, data from each site were looked at independently, so that site-specific differences in the relationship between elevation and inundation could be removed. Results of correlation analysis show that the relationship is stronger between elevation and plant community structure for each of these sites alone than for all sites combined (see Tables 7 and 8 to compare correlation coefficients), which is consistent with the hypothesis that inundation duration and frequency for a given elevation differs between sites. Plots of elevations and cover types for the Welder Flat Grid 2 site and the ANWR Grid 2 site also support the paradigm of a link between elevation and plant community structure much more strongly than plots for all sites combined, which is again consistent with the hypothesis that inundation duration and frequency for a given elevation differs between sites (Figure 13). However, even when individual sites are considered, r^2 values are relatively low, suggesting that elevation is at best a poor predictor of vegetation community structure.

While it is not possible to unequivocally state causes for the poor relationship between elevation and plant community structure, two explanations seem most reasonable: 1) While part of the variability in community structure at the project site may be driven by elevation differences, other factors, such as interspecific interactions, grazing, soil conditions, and seed set, are also involved, and 2) the expected relationship between elevation and plant community structure is weakened when data from all sites are combined because similar elevations at different sites experience different inundation frequencies and duration. These explanations gain further credence from data available in the scientific literature exploring the relationship between mean tide ranges and elevations at which *Spartina alterniflora* occurs at sites around the East and Gulf Coasts (Figure 14).

How can this information contribute to created marsh design? First, it suggests that target elevations should to be taken from nearby natural marshes that appear to have similar tidal exposure to the created wetland being designed. Second, it suggests that attainment of target elevations will not guarantee development of specific plant communities, and that performance standards should retain sufficient flexibility to account for this

Table 7. Correlation matrix for commonly occurring plant species and elevation. Correlation coefficients marked in bold are significant at $p < 0.05$ ($n = 288$). Analysis used case-wise deletion of missing data.

	Elevation	Bare ground	Aster tenuifolius	*Batis maritima*	*Borrichia frutescens*	*Distichlis spicata*	*Lycium carolinianum*	*Monanthochloe littoralis*	*Salicornia virginica*	*Scirpus c.a. americanus*	*Spartina alterniflora*	*Spartina spartinae*
Elevation	1.00											
Bare ground	**-0.26**	1.00										
Aster tenuiflius	0.00	-0.07	1.00									
Batis maritima	**-0.14**	0.01	-0.05	1.00								
Borrichia frutescens	-0.08	-0.02	-0.04	**-0.37**	1.00							
Distichlis spicata	**-0.14**	**-0.21**	0.00	**-0.16**	**-0.14**	1.00						
Lycium carolinianum	0.03	-0.10	-0.03	-0.04	-0.05	-0.06	1.00					
Monanthochloe littoralis	**0.18**	**-0.53**	-0.03	**-0.15**	**-0.18**	-0.08	**0.18**	1.00				
Salicornia virginica	**0.36**	**-0.22**	**0.25**	**-0.16**	-0.10	**-0.12**	-0.06	-0.10	1.00			
Scirpus c.a. americanus	-0.07	0.07	-0.01	-0.07	0.10	-0.04	0.02	-0.04	0.00	1.00		
Spartina alterniflora	0.03	0.06	-0.02	**-0.30**	**-0.19**	**-0.13**	**-0.12**	**-0.15**	-0.06	-0.03	1.00	
Spartina spartinae	**0.21**	**-0.17**	-0.01	-0.10	-0.02	-0.04	-0.03	-0.02	-0.01	-0.01	-0.03	1.00

Table 8. Correlation coefficients for dominant vegetation and elevation from Welder Flat Grid 2 and ANWR Grid 2. Correlation coefficients are all significant at $p < 0.05$ ($n = 40$). Comparison of correlation coefficients suggests that the relationships between the two dominant plant species for Welder Flat Grid 2 and Aransas National Wildlife Refuge Grid 2 and elevation are much stronger than relationships found for data collected throughout the project area (see Table 6), despite the smaller sample size. This is consistent with the hypothesis that "The expected relationship between elevation and plant community structure is weakened when all sites are combined because similar elevations at different sites experience different inundation frequencies and duration."

	Welder Flat Grid 2 Elevation	ANWR Grid 2 Elevation
Batis maritima	0.34	-0.61
Spartina alterniflora	-0.50	—
Monanthochloe littoralis	—	0.71

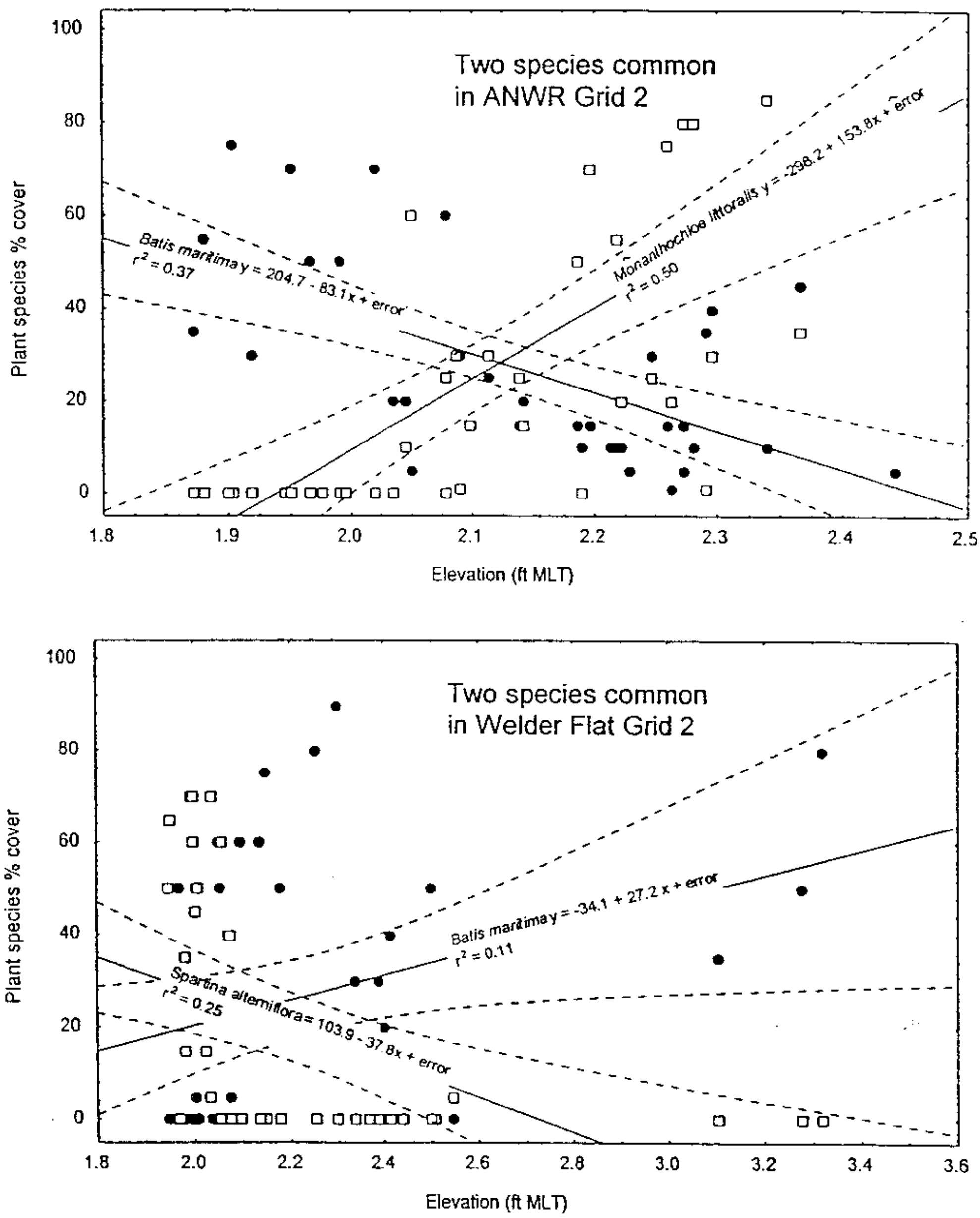


Figure 13. For individual grids (Welder Flat Grid 2 and ANWR Grid 2), data are more consistent with the paradigm linking elevation and plant community structure than is the case when data from all sites are compared. Nevertheless, r^2 values are low, indicating that factors other than elevation play a role in plant community structure. Circles represent *Batis maritima*, while open squares represent *Spartina alterniflora* (bottom) *and Monanthochloe littoralis* (top).

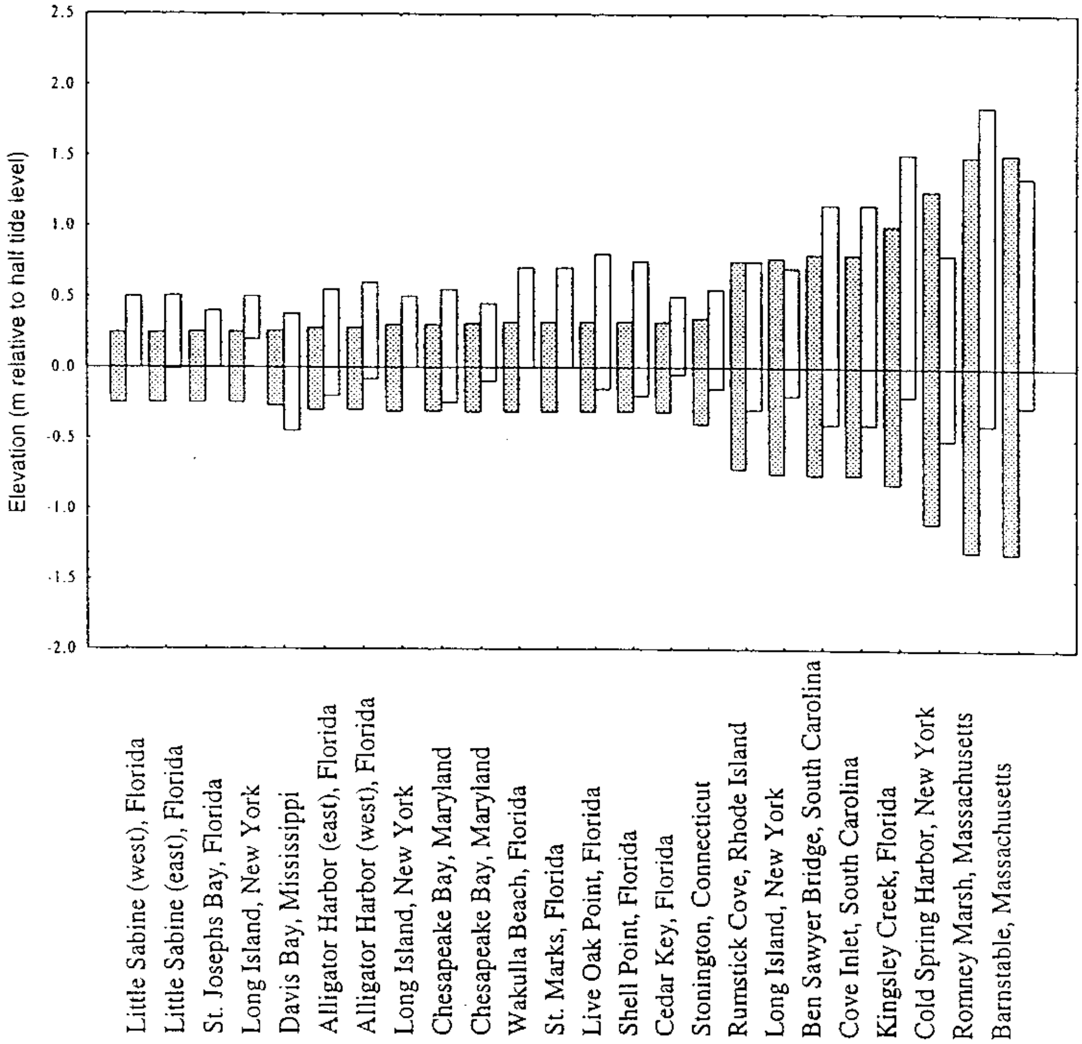


Figure 14. The Mean Tide Range (MTR) (filled bars) and the Growth Range for *Spartina alterniflora* (unfilled bars) from a number of sites around the East and Gulf Coasts. The Growth Range is the range of elevations where *S. alterniflora* occurs. The 0-m elevation is set to the half tide level, midway between mean high water and mean low water. Data are from various published studies. Mean Tide Ranges are based on tide gauge data, while Growth Ranges are from on-site observations using various surveying techniques. Data can be interpreted in at least two ways:

1. *S. alterniflora* growth ranges may vary, relative to Mean Tide Range, at different sites for a number of reasons, such as competitive interactions with other plants, intraspecific genetic differences in *S. alterniflora* from different areas, different soil conditions, and different salinities.
2. Mean Tide Ranges from tide gauge data may not be representative of conditions on the sites where Growth Ranges were measured. Estuarine geomorphology can funnel tides into some areas and restrict tides from other areas, and tidal attenuation will increase as distance from the main body of the estuary increases.

These interpretations are not mutually exclusive, and both may be valid. These data reinforce the limitations of marsh ecology paradigms that strictly link elevation relative to measured tide ranges with plant species distribution. Although similar data are not available for other plant species, the variability seen for *S. alterniflora* occurrence relative to tide ranges is likely to be found for other species as well, and this trend is consistent with field data from the project site. (Adapted from McKee and Patrick 1988.)

variability. (Note that performance standards as currently written will account for the degree of variability found in the field data.)

Landscape-level Geomorphology

As noted earlier in this report, the term "landscape-level geomorphology" is used to describe the geomorphology that can be determined from aerial photographs. A series of 1991 aerial photographs was obtained from Aransas National Wildlife Refuge. Cursory examination of aerial photographs shows that landscape-level geomorphology varies across the project site. For example, water-filled depressions and tidally connected pools make edge-area ratios higher in parts of Welder Flat than in parts of Aransas National Wildlife Refuge (Figure 15). To imitate the variability that exists across the project site, site design should be based on specific locations within the project site, rather than means of statistics summarizing landscape-level geomorphology based on the project site as a whole.

Various statistics that summarize landscape geomorphology, such as pond density and edge:area ratio, were not computed for this study. A study by Rozas and Zimmerman (1994) was identified in which a number of summary statistics were generated from three sites near Galveston Bay, and these statistics are presented in Table 9 for reference purposes. Similar statistics can be generated from project site aerial photographs or DOQQs if needed. Summary statistics will be needed to assess attainment of performance standards, but those statistics should be from recent DOQQs taken after site construction (as per Table 3). For design purposes, direct use of aerial photographs is more desirable than reliance on summary statistics, because summary statistics, which inevitably mask certain information and will not be fully representative of site conditions, may introduce design errors (see Conceptual Design and Detailed Design sections of this report).

Aerial photographs of parts of the project site suggest that at least some of the marsh habitat may be affected by subsidence (especially in parts of Welder Flat), and that open water areas and marshes with high edge:area ratios may reflect the results of subsidence (Figure 15). If open water areas and marshes with high edge:area ratios do reflect the results of subsidence, and subsidence has not stabilized, ongoing subsidence will lead to continued replacement of marsh with open water. Similarly, if created marshes are designed to mimic natural marshes affected by subsidence, created marshes may be replaced by shallow open water habitat over time. The time frame of subsidence at the project site is unknown. Analysis of a time series of aerial photographs, if aerial photographs are available, may indicate whether or not subsidence is in fact occurring and may allow an estimate of rates of marsh loss. Alternatively, installation of sediment-erosion tables (see Cahoon and Lynch 1997) would allow direct estimates of subsidence rates.

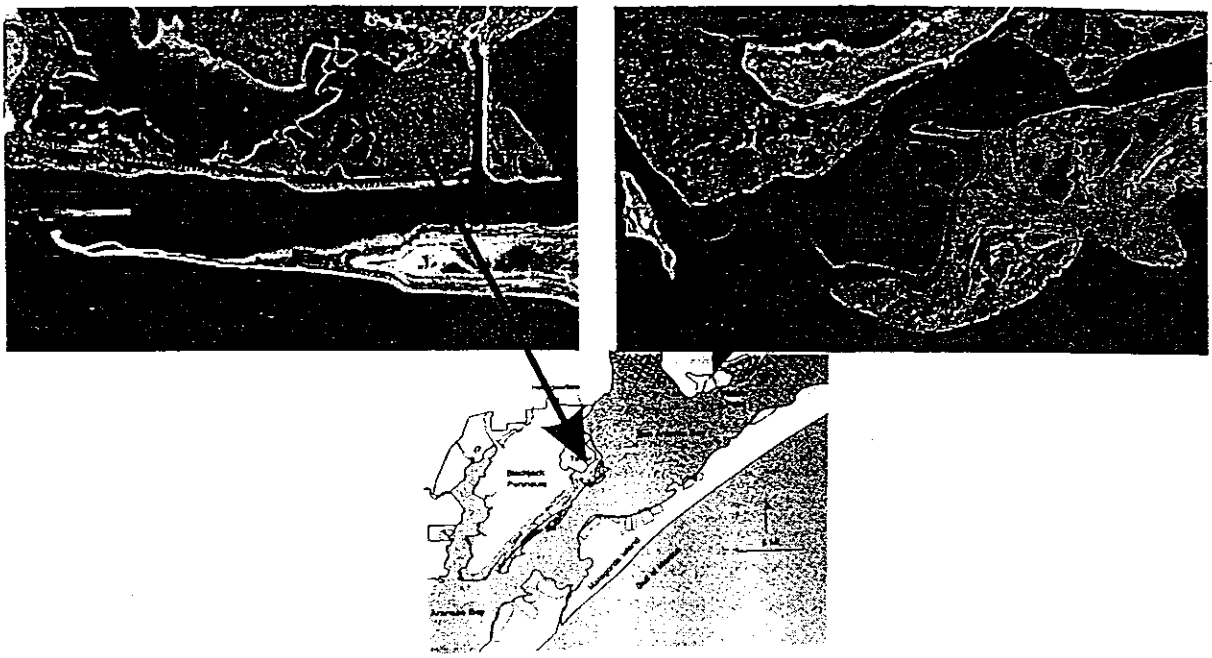


Figure 15. Aerial photographs show significant development of ponds and shallow depressions with few well-developed tidal creeks, especially at Welder Flat (top right). Development of scattered ponds suggests that sites may be undergoing long-term subsidence (see, for example, Gosselink 1984).

Table 9. Statistics summarizing landscape-level geomorphology of three Galveston Bay sites. Summary statistics are based on interpretation of aerial photographs. Adapted from Rozas and Zimmerman 1994.

	Site		
Statistic	Atkinson Island	Hog Island	Cedar Point
Total number of ponds	33	52	20
Total pond perimeter (m)	2,263	3,701	1,703
Total pond area (m^2)	18,389	57,780	14,583
Total number of channels	28	10	17
Total channel length (m)	1,241	1,043	1,037
Total channel area (m^2)	4,760	3,728	6,188
Total cove number	3	1	1
Total cove area (m^2)	79,248	26,377	12,259
Total length of shoreline (m)	8,009	6,489	5,491
Total area of site (m^2)	454,564	263,193	205,093
Total area of upland (m^2)	8,831	9,877	22,427
Total area of marsh (m^2)	343,335	165,430	149,636
Total area of open water (m^2)	102,398	87,886	33,030
Marsh:Open water	3.4	1.9	4.5
Pond density (ponds per ha of marsh)	1.0	3.1	1.3
Channel density (channels per ha of marsh)	0.8	0.6	1.1

III. Testing Vegetation Performance Standards with Field Data

Performance standards described in Table 3 of Section 1 in this report address a number of project features. Monitoring of most of the performance standards relies on standard methods. However, two of the vegetation performance standards suggested during the 3-4 November 1998 ICT meeting rely on methods that require testing. The first of these performance standards called for a similarity index of 0.6 or greater between created and natural marsh sites, based on computation of a similarity index using areal percent cover data from at least 40 1-m^2 quadrats at the created wetland and a nearby natural reference site (see Table 3, including footnotes). The second of these performance standards called for similar patchiness in created and natural marsh sites as determined by achieving mean diversity within 1-m^2 quadrats that is within 50% of mean diversity in natural wetlands, based on mean areal percent cover data from at least 40 quadrats and application of the Shannon-Wiener diversity index (see Table 3, including footnotes).

This section explains the rationale for these performance standards, explains why these performance standards require testing, and tests the performance standards using both actual data from the field and data generated on a computer.

The Similarity Performance Standard

A Primer on Similarity

Similarity indexes have long been used by ecologists to determine the degree to which two sets of samples share a common species list or a common species list and same-species abundances. Similarity indexes form the basis of more complex analyses, such as most forms of classification analyses (clustering) and most forms of ordination (such as Principle Components Analysis, Principle Coordinates Analysis, and Canonical Correspondence Analysis), but they can also be used to generate a similarity matrix that summarizes the degree to which two or more samples are "similar." Similarity indexes typically use an algorithm to generate a value between 0 and 1 for each comparison. Values approaching 0 suggest that the two sets of samples being compared have very little in common, while values approaching 1 suggest that the two sets of samples being compared have a great deal in common. Worded another way, values approaching 0 suggest that the two sets of samples come from different kinds of communities, while values approaching 1 suggest that the two sets of samples come from the same kind of community.

The simplest similarity index, sometimes called Sorensen's Similarity Index or the Coefficient of Sorensen, is based entirely on species lists; that is, the index only considers presence or absence of a species in each sample or set of samples. To compute the Sorensen's Similarity Index for sample sets A and B:

$$S = 2a / (2a + b + c),$$

where S is the Sorensen's Similarity Index, a is the number of species that occur in both sample set A and sample set B, b is the number of species that occur in sample set B but not A, and c is the number of samples that occur in sample set A but not B.

The following simple data set can be used as an example:

	Sample W	Sample X	Sample Y	Sample Z
Species 1	present	present	present	absent
Species 2	present	present	absent	present
Species 3	present	present	absent	present
Species 4	present	present	absent	present

Using presence and absence data from this data set, the following similarity matrix can be generated:

	-Sample W	Sample X	Sample Y	Sample Z
Species 1	-			
Species 2	1	-		
Species 3	0.4	0.4	-	
Species 4	0.86	0.86	0	-

Sample W and X are identical, and therefore have a similarity of 1. Sample Z shares three of four species with W and X, and has a similarity to both W and X of 0.86, suggesting that it is very similar but not the same as Samples W and X (i.e., the value 0.86 is close to 1, so the samples must be fairly similar). Sample Y shares one species with Samples W and X, and its similarity to these samples is only 0.4. Sample Y and Z share no species in common, and therefore have a similarity of 0.

Sorensen's Similarity Index is presented only as an illustration. Performance standards for the created wetlands require use of a quantitative similarity index-that is, an index that can account for both the species identity (which species are present or absent) and the number of individuals, or in this case the areal cover, of each species. An appropriate index for this purpose is the Simplified Morisita Index:

$$S = \frac{2\Sigma X_{ij} X_{ik}}{[(\Sigma X^2_{ij} / N^2_{j}) + (\Sigma X^2_{ik} / N^2_{k})]\, N_j N_k},$$

where S is the simplified Morisita Index, X_{ij} and X_{ik} are the number of individuals of species i in sample j and sample k, N_j is the total number of individuals in sample j, and N_k is the total number of individuals in sample k. The Simplified Morisita Index yields values from 0, for no similarity between samples, to about 1, for complete similarity. Note that many similarity indexes cannot be used with percent areal cover data, because they were designed for count data. The Simplified Morisitas Index is one of the few similarity indexes that can be used with percent areal cover data.

The Simplified Morisita Index value can be interpreted as a ratio of two probabilities:

probability that an individual drawn from sample j and from sample k will be the same species/
probability that 2 individuals drawn from either sample j or k will be the same species

A number of basic ecology text books discuss similarity indexes, including Krebs (1989) and Southwood (1978). In addition, many papers in the scientific literature discuss various similarity indexes and their behavior in different circumstances (for example, see Wolda 1981).

Rationale behind the Similarity Performance Standard

The similarity performance standard is intended to prevent creation of marshes with plant communities dramatically different (in terms of species present and their abundance) from those of natural marshes. Sites 127a and 128 are dominated by *Spartina alterniflora*. Although *Spartina alterniflora* marshes occur in the project area, they do not, in general, cover large areas. Concerns that created marshes might be dominated by *Spartina alterniflora* in particular drove the inclusion of a similarity performance standard.

Why the Similarity Performance Standard needs Testing

It is important to realize that two sets of randomly collected samples from a single community will not be identical to one another. This is because of the natural variability that exists within plant communities. Just as any one randomly selected sample is not going to be identical to any other randomly selected sample, any one set of randomly collected samples will not be identical to any other set of randomly collected samples. As the size of a sample set increases (that is, as the number of samples in the sample set increases), the ability of the sample set to represent the entire community increases. When two relatively small sample sets from the same community are compared, the natural variability in the community is likely to be reflected in a low similarity index value. With a sufficiently large set of pilot data, a self-similarity curve can be generated in which the similarity between progressively larger pairs of sample sets from the same community are compared until the similarity values begin to plateau, indicating that the sampling effort is sufficient to overcome most of the natural variability in the community (see Streever and Bloom 1993). Unless a self-similarity curve is generated, a predetermined sampling effort will have to be accepted, with the assumption that the sampling effort can adequately represent the natural variability of the marsh. While this is not necessarily an ideal approach, it is a commonly adopted approach in sampling design.

Stated more directly, sample size will affect similarity. When all else is equal, smaller sample sizes may yield lower similarity values than larger sample sizes. This is an important point, because low similarity may reflect differences between two communities (for example, between the plant community of a natural wetland and the plant community of a created wetland) or it may reflect variability within a community that is not captured by the sampling effort. However, it should also be noted that in the case of two distinctly different communities, increasing sampling effort will not increase similarity indefinitely. Once the sampling effort is sufficient to adequately capture the variability within a community, increasing sampling effort will not increase similarity values.

Prescribed similarity values are sometimes required as performance standards for compensatory mitigation required on Section 404 permits (see Streever 1999, example 18 in Table 1). The similarity value for these performance standards seems to be arbitrarily set or at least set on the basis of past experience rather than on the basis of well-reasoned analysis or trials with pilot data. In many cases, permits require attainment of specific similarity values but do not specify the required sampling effort or even the similarity index to be used. Similarly, a performance standard for the 50-year DMMP project wetlands was set at 0.6 (that is, a similarity of 0.6 between nearby natural and created wetlands) during the 3-4 November 1998 ICT meeting, based on past experience but without a well-reasoned analysis or trial. Without testing, the value of 0.6 set as a performance standard may be unreasonably high (i.e., it may be higher than the similarity typically seen between two areas of natural marsh sampled using the prescribed 40-quadrat method). Alternatively, the value of 0.6 may be unreasonably low, allowing created marshes that do not have reasonable similarity to natural marshes to meet the performance standard.

Testing the Similarity Performance Standard

Data from the three Aransas National Wildlife Refuge grids, the two Welder Flat grids, and three created data sets were used to test the similarity performance standard. For each grid, areal cover data from 40 1-m^2 quadrats were used. For grids with more than 40 1-m^2 quadrats, the first 40 1-m^2 quadrats were used. Created data sets consisted of cover values for 40 1-m^2 quadrats. "Monoculture" mock data is a created data set in which a single plant species (*Batis maritima*) and bare ground were present, with percent contribution of *Batis maritima* varying from 35% to 95% (with a mean cover of 50%); "monoculture" mock data represents a situation in which a single high marsh plant species survives. "Triculture" mock data is a created data set in which three plant species (*Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*) and bare ground were present, but only one plant species was present in any one quadrat, and with percent contribution of plant cover varying from 35% to 95% within a quadrat (each species had a mean cover of 16.66%, or 50% for the quadrats in which each species occurred); "triculture" mock data represents a situation in which plants are distributed with an unnatural zonation (or an aggregated distribution), as could occur following planting of mixed species. *Spartina alterniflora* monoculture mock data is a created data set in which *Spartina alterniflora* and bare ground were present, with percent contribution of *Spartina alterniflora* varying from 35% to 95% (with a mean of 50%);

Spartina alterniflora mock data represents a situation similar to that which has actually occurred across much of Sites 127a and 128.

Table 10 presents similarity values (Simplified Morisita Index similarity values) between the grids. Similarity values were created using Community Analyses System 5.0 software (Ecological Data Consultants, Inc.). Similarity values ranged from 0.42 to 0.96. Similarity values between the *Spartina alterniflora* monoculture grid and grids with actual field data ranged from 0.42 to 0.74. That is, similarity was not always below the required 0.6 set for the performance standard during the 3-4 November 1998 ICT meeting. Furthermore, several comparisons of actual data for wetlands in the project area also yielded similarity values below 0.6 (for example, Aransas Gird 2 and Aransas Grid 3 had a similarity of 0.48). With this in mind, it would not be reasonable to use the similarity performance standard without some modification.

Part of the reason for high similarity values among all sites was inclusion of the bare ground cover type in comparisons. Bare ground made a substantial contribution to areal cover at all sites, but because it can occur in any plant community its contribution to the assessment of created wetlands may be questionable. Re-analysis of the data with the bare ground cover class excluded was used to generate the similarity matrix in Table 11. With the bare ground cover class excluded, the *Spartina alterniflora* data set has a similarity of 0 to all actual grids except Welder Flat Grid 2, which was the only grid where *Spartina alterniflora* occurred;. comparison of the *Spartina alterniflora* monoculture data and the Welder Flat Grid 2 data was 0.41, lower than the 0.6 value required by the performance standard. However, many of the natural wetland comparisons also failed this performance standard. For example, ANWR Grid 1 and Welder Flat Grid 1 had a similarity value of 0.32, and ANWR Grid 2 and Welder Flat Grid 2 had a similarity value of 0.25.

Even when the bare ground cover class is excluded from the analysis, the similarity performance standard cannot consistently differentiate between comparisons of undesirable, unnatural plant communities and natural plant communities, on the one hand, and pairs of natural wetlands on the other hand. In short, there is little point in using the similarity performance standard.

If the similarity performance standard is abandoned, it should be replaced by a performance standard capable of identifying problems with vegetation community composition. The similarity performance standard was originally advocated (during the 3-4 November 1998 ICT meeting) as a means of preventing *Spartina alterniflora* monocultures, such as that of PA 127a, from being accepted as part of the ongoing wetland creation program. As explained in the following section, the diversity performance standard will prevent acceptance of monocultures of any species, including *Spartina alterniflora.* In addition to relying on the diversity performance standard to prevent acceptance of monocultures, the similarity performance standard was replaced with a performance standard requiring the presence of at least 20% cumulative cover by *Batis maritima*, *Borrichia frutescens*, *Monanthochloe littoralis*, *Salicornia* spp., and/or *Lycium carolinianum*, with the additional requirement that *Lycium carolinianum* should be present at all sites. This performance standard would be met by all transect data and grid data collected during 8-10 December 1998 field visits, but the three mock data sets would all fail. *Spartina alterniflora* monocultures such as those of PA's 127a and 128 would not meet this performance standard. Based on data presented in Darnell et al.'s (1997) Table 5, three additional natural wetlands would pass this performance standard, but PA's 127a and 128 would fail. (Of course, it would be unfair to judge PA's 127a and 128 based on this performance standard, because they were not designed to be similar to nearby natural marshes. They are simply cited here as examples of the kind of created wetlands that would not pass this performance standard.)

In Table 3, the similarity performance standard suggested during the 3-4 November 1998 ICT meeting was replaced with the performance standard stating that "At least 1/5 of total cover (inclusive of bare ground) will be by *Batis maritima*, *Borrichia frutescens*, *Monanthochloe littoralis*, *Salicornia* spp., and/or *Lycium carolinanum*, and *Lycium carolinanum* will be present."

The Diversity Performance Standard

A Primer on Diversity

Biological diversity in the context intended here is a measure of community complexity based on species, or, put another way, the species variability in a community. In a very diverse community, the likelihood of finding the same species in two randomly selected samples is very low. In a community with very low diversity, the likelihood of finding the same species in two randomly selected samples is very high. In a monoculture, which has the lowest possible diversity, every sample will have the same species (that is, every sample will have the only species that occurs in the community).

The simplest measure of diversity is simply species richness, or the number of species that occur in an area. Using this measure of diversity, a community with ten species is considered more diverse than a community with three species. However, this simple approach makes no provision for relative abundance of species. For example, consider two communities, each of which has 10 species and 1,000 individuals. Community 1 has 991 individuals of species a, and one individual representing each of the other nine species. Community 2 has 100 individuals of each species. Based only on species richness, the two communities have the same diversity, but anyone sampling the two communities would probably find Community 2 to be more complex. Also, an organism in Community 2 would tend to have more complex interactions, in the sense that it would have a higher likelihood of encountering different species than would its counterpart in Community 1.

With this in mind, diversity indexes were developed that account for species abundance as well as species

Table 10. Similarity matrix comparing similarity of vegetation grids from project site and three mock data sets. The "monocutlure" mock data set was constructed as a monoculture of *Batis maritima* (mean = 50%) with some bare ground (mean = 50%), such as might occur if only *Batis maritima* survived on the created sites. The "triculture" mock data set was constructed to represent a site with bare ground (mean = 50%) and several monocultures (*Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*, each with a mean of 16.6%), divided across the marsh in such a way that any one quadrat would only sample one species, such as might occur if vegetation grows in clearly defined zones rather than as a mosaic. The *Spartina alterniflora* monoculture data set was constructed to represent a site with only *Spartina alterniflora* (mean = 50%) and bare ground (mean = 50%), similar to parts of the existing created wetlands at sites 127a and 128. The similarity index used was the Simplified Morisita Index (also known as "Horn's Modification of the Morisita Index"), which can be applied to percent areal cover data.

	Aransas Grid 1	Aransas Grid 2	Aransas Grid 3	Welder Flat Grid 1	Welder Flat Grid 2	"Monoculture" Mock Data	"Triculture" Mock Data	*Spartina alterniflora* monoculture
Aransas Grid 1	1							
Aransas Grid 2	0.71	1						
Aransas Grid 3	0.93	0.48	1					
Welder Flat Grid 1	0.77	0.89	0.54	1				
Welder Flat Grid 2	0.77	0.86	0.55	0.91	1			
"Monoculture" Mock Data	0.72	0.79	0.52	0.96	0.86	1		
"Triculture" Mock Data	0.93	0.75	0.81	0.87	0.82	0.79	1	
Spartina alterniflora monoculture	0.55	0.42	0.46	0.49	0.74	0.50	0.6	1

Table 11. Similarity matrix comparing similarity of vegetation grids from project site and three mock data sets, with bare ground cover class data removed. Mock data sets are the same as those described for Table 10, but with the bare ground cover class data removed.

	Aransas Grid 1	Aransas Grid 2	Aransas Grid 3	Welder Flat Grid 1	Welder Flat Grid 2	"Monoculture" Mock Data	"Triculture" Mock Data	*Spartina alterniflora* monoculture
Aransas Grid 1	1							
Aransas Grid 2	0.73	1						
Aransas Grid 3	0.91	0.47	1					
Welder Flat Grid 1	0.32	0.63	0.11	1				
Welder Flat Grid 2	0.25	0.54	0.09	0.81	1			
"Monoculture" Mock Data	0.29	0.53	0.09	0.86	0.65	1		
"Triculture" Mock Data	0.50	0.42	0.48	0.72	0.54	0.56	1	
Spartina alterniflora monoculture	0	0	0	0	0.41	0	0	1

richness. Over time, the Shannon-Wiener Diversity Index (sometimes incorrectly called the Shannon-Weaver Index) became the most popular of the many diversity indexes available. The Shannon-Weiner Diversity Index is:

$$H' = \Sigma\ (p_i)\ (\log_{10} p_i)\qquad ,$$

where H' is the Shannon-Wiener Diversity Index value and p_i is the proportion of the total sample belonging to the ith species. In this representation of the Shannon-Weiner Diversity Index, base 10 logarithms are used, but base 2 or base *e* logarithms have also been used, and comparisons of Shannon-Weiner Diversity Index values from different studies may need to standardized to a common base. This can be done through standard conversion factors available in many texts. Shannon-Weiner Diversity Index values derived using base 10 logarithms are sometimes reported in units called "decits."

Shannon-Weiner Diversity Index values will range from 0 (for a community with one species) to some larger value, although data from actual community sampling seldom leads to Shannon-Weiner Diversity Index values exceeding about 2 decits.

A number of basic ecology text books discuss diversity indexes, including Krebs (1989) and Southwood (1978). In addition, many papers in the scientific literature discuss various diversity indexes and their behavior in different circumstances (for example, see Hurlbert 1971 and Washington 1984).

Rationale for the Diversity Performance Standard

In many instances, diversity is of interest as a community attribute. For example, the diversity of benthic invertebrate communities can be used as an indicator of water quality; in freshwater streams, relatively high diversity of benthic invertebrates indicates clean water, while low diversity indicates polluted water (to be more precise, high diversity indicates high dissolved oxygen levels, while low diversity indicates low dissolved oxygen levels, which are usually associated with organic sewage in freshwater streams). As a performance standard for wetlands created under the 50-year DMMP, diversity in itself is <u>not</u> of interest as a community attribute. Instead, the Shannon-Weiner Diversity Index is used as a means of assessing the degree to which planted species occur in mixed stands in areas less than 1 m^2.

In natural marshes of the project area, three or more species and bare ground are likely to occur in a single 1-m^2 quadrat. The ICT expressed some concern that marshes planted on dredged material would not have the same level of intermixing of species. In fact, given standard planting techniques of no more than 1-m centers for planting, it seems unlikely that plant communities will have the same degree of intermixing until enough time has passed to allow spread of plants (vegetative spread and spread via seeds) even if initial plantings are intentionally mixed.

To measure the degree of intermixing of species in areas less than 1 m^2, some quantitative index had to be developed. After some consideration, it was suggested that mean diversity could be compared between created and natural marshes to determine if created marshes had the same degree of intermixing that occurred in created marshes. That is, the diversity of each 1-m^2 quadrat of a grid would be computed and a mean diversity for the grid would be computed based on the diversity of all quadrats in the grid. Initially, the ICT suggested that the performance standard should require the mean diversity of created sites to be within 50% of that of natural sites.

Why the Diversity Standard needed Testing

To the knowledge of ICT members, no standard methods are available to assess intermixing of herbaceous plant species on this scale (although various methods are available at other scales). Use of mean diversities in 1-m^2 quadrats as a measure of intermixing of species is a new method. As such, it should not be used without testing.

Testing the Diversity Performance Standard

Data from the three Aransas National Wildlife Refuge grids, the two Welder Flat grids, and three created data sets were used to test the diversity performance standard. For each grid, areal cover data from 40 1-m^2 quadrats was used. For grids with more than 40 1-m^2 quadrats, the first 40 1-m^2 quadrats were used. Created data sets consisted of cover values (cover values were included for each plant species and bare ground) for 40 1-m^2 quadrats. "Monoculture" mock data is a created data set in which a single plant species (*Batis maritima*) and bare ground were present, with percent contribution of *Batis maritima* varying from 35% to 95% (overall mean = 50% cover); "monoculture" mock data represents a situation in which a single high marsh plant species survives. "Triculture" mock data is a created data set in which three plant species (*Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*) and bare ground were present, but only one plant species was present in any one quadrat, and with percent contribution of plant cover varying from 35% to 95% within a quadrat (with a mean of 16.66% for each species, or 50% for each species within the quadrats that the species occurs); "triculture" mock data represents a situation in which plants are distributed with an unnatural zonation (or an aggregated distribution), as could occur following planting of mixed species. *Spartina alterniflora* monoculture mock data is a created data set in which *Spartina alterniflora* and bare ground were present, with percent contribution of *Spartina alterniflora* varying from 35% to 95% (with an overall mean of 50% cover); *Spartina alterniflora* mock data represents a situation similar to that which has actually occurred across much of Sites 127a and 128.

Shannon-Wiener Diversity Index values (base 10 logarithms) were computed for each quadrat; thus, there

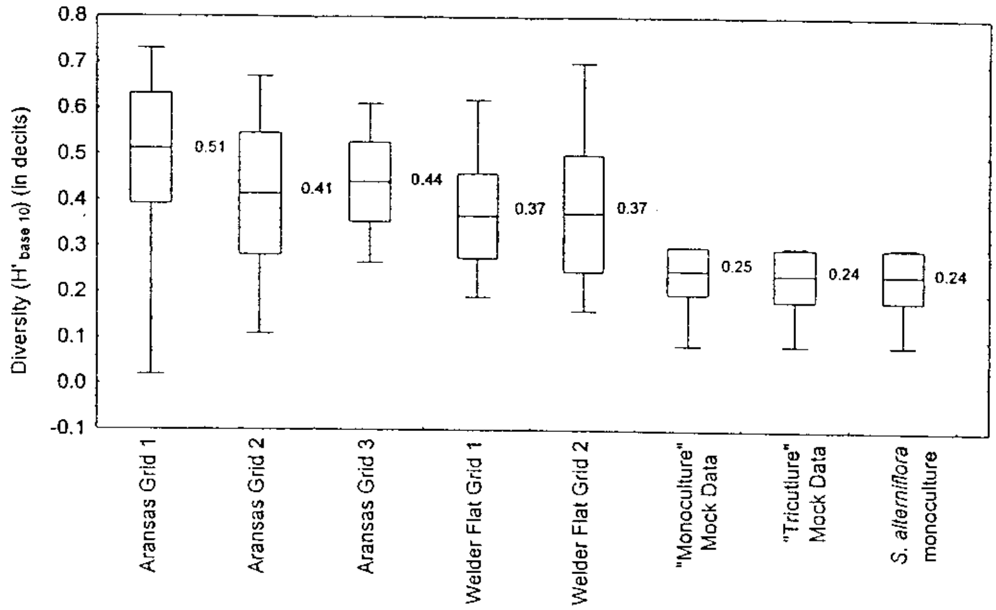


Figure 16. Diversity comparisons of grids and mock data. Horizontal line represents mean diversity, boxes represent standard deviations, and whiskers represent ranges. Means, standard deviations, and ranges are based on 40 1-m^2 quadrats from each grid. The diversity index used is the Shannon-Wiener (also called Shannon-Weaver) diversity index, with base 10 logs. "Monoculture" mock data is a created data set in which a single plant species (*Batis maritima*) and bare ground were present, with percent contribution of *Batis maritima* varying from 35% to 95% (mean = 50% cover by *Batis maritima*); "monoculture" mock data represents a situation in which a single plant species survives. "Triculture" mock data is a created data set in which three plant species (*Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*, each occurring with mean = 16.66%) and bare ground were present, but only one plant species was present in any one quadrat, and with percent contribution of plant cover varying from 35% to 95% within a quadrat; "triculture" mock data represents a situation in which plants are distributed with an unnatural zonation (i.e., an aggregated distribution). *Spartina alterniflora* monoculture is a created data set in which *Spartina alterniflora* occurs with cover varying from 35% to 95% (mean = 50%). A comparison of diversity values from the mock data sets with those of the actual data sets shows that mean diversity can act as an indicator of patchiness for assessment of created wetland plant communities.

were 40 Diversity Index values for each grid, and a total of 320 Diversity Index values. Diversity Index values were computed using Community Analyses System 5.0 software (Ecological Data Consultants, Inc.). For each grid, means, standard deviations, and ranges were computed. Summarized Diversity Index values are presented in Figure 16. Mean Diversity Index values for data from actual grids ranged from 0.37 to 0.51, while mean Diversity Index values for mock data, representing situations where species patchiness was less than that of natural marshes, ranged from 0.24 to 0.25. The similarity of Mean Diversity Index values for mock data is not surprising, since diversity in individual quadrats of the mock data sets would have been similar (because no quadrat in the mock data had more than one species and bare ground).

The diversity performance standard initially advocated during the 3-4 November 1998 ICT meeting called for "Similar patchiness in created and natural marsh sites as determined by achieving mean diversity within 1-m^2 plots in created wetlands that is within 50% of mean diversity in natural wetlands." Mean Diversity Index values from mock data sets were not below the 50%-difference threshold required in this performance standard. This performance standard, as initially stated, would not adequately address problems with low intermixing of species. A better performance standard would be "Similar patchiness in created and natural marsh sites as determined by achieving mean diversity within 1-m^2 plots in created wetlands that is within the range of mean diversity in natural wetlands." Based on this assessment, the performance standard was changed as noted here (see Table 3).

IV. Conceptual Design: Self-organizational Theory, Adaptive Management, Planting, Structures, and Coordinating Dredging Cycles

In this section, several issues relevant to design of all sites to be created as part of the 50-year DMMP are discussed. These issues include self-organizational theory, adaptive management, planting, structures, and coordinating dredging cycles.

The U.S. Army Corps of Engineers and others have been creating marshes on dredged material and other substrates for three decades (see, for example, Kusler and Kentula 1990, Landin et al. 1989). During this time, a great deal has been learned from both experience with marsh creation projects and research. Approaches to wetland creation are still evolving, as are generally accepted beliefs regarding the acceptability of end products and the certainty with which project outcomes can be predicted. For example, a salt marsh that was created on dredged material in the early 1970s may have been considered a resounding success, but by today's standards the same marsh may be considered little more than a marginal success. In the past, establishment of a plant community that resembled natural marsh plant communities frequently constituted a success. Currently, for a created marsh to be considered successful it should 1) support a plant community that is similar to natural marsh plant communities, 2) support invertebrate and vertebrate (fish and bird) communities similar to those of natural marshes, 3) have soils with characteristics similar to those of natural marshes, and 4) have a geomorphology similar to that of natural marshes, including occurrence of tidal creeks and pools and the absence of high ground.

This section summarizes a number of issues that will affect the design of all wetland sites to be created as part of the 50-year DMMP. Information in this section is drawn from the scientific literature as well as experience with existing sites. Experience from sites created near the Aransas National Wildlife Refuge is emphasized. These sites include three wetlands created by Mitchell Energy Corporation (MEC) in 1991, 1993, and 1995, and two sites created by the US Army Corps of Engineers in 1993. The MEC sites were built by placing dredged material inside of earthen dikes protected by articulated concrete mattresses near Mesquite Bay, about 60 m from Bludworth Island (at N 28°09.337', W 96°52.756'). Wynne Channel, near the northeast end of Bludworth Island, and a nearby drilling basin were the sources of dredged material for the MEC sites (Darnell et al. 1997). In general, grain size of the dredged material used to create the MEC sites was larger than the grain size that is expected in material resulting from maintenance dredging of the Gulf Intracoastal Waterway in the project area. The two sites created by the US Army Corps of Engineers, Sites 127a and 128, were constructed using material from maintenance dredging of the Gulf Intracoastal Waterway. Site 127a, located near False Live Oak Point in San Antonio Bay (at N 28°13.540', W 96°47.320'), was created by pumping dredged material into an area confined by an earthen dike and protected by a riprap breakwater. Site 128, located about 1 km northeast of Rattlesnake Island in Ayers Bay (at N 28°12.763', W 96°48.856') was created by pumping dredged material into an area confined by geotextile tubes and an existing dredged material island. Because Sites 127a and 128 were created from sediment that is similar to that which is expected to result from further proposed maintenance dredging, they provide a reasonable model for sites that will be built as part of the 50-year DMMP in terms of sediment characteristics. However, portions of the vegetation communities of Sites 127a and 128 are dominated by *Spartina alterniflora*, and are not representative of the desired plant communities for wetlands planned as part of the 50-year DMMP, apparently because elevations at Sites 127a and 128 are too low to support high marsh species such as *Batis maritima*, *Borrichia frutescens*, and *Lycium carolinianum*. In the relatively high elevations of Sites 127a and 128, as well as high elevations of the MEC sites, high marsh species do occur.

Self-organizational Theory and Site Designs

The definition of "success" and ways of measuring "success," in the context of wetland creation, is an area of ongoing discussion within the scientific and conservation literature. For the wetlands established as part of the 50-year DMMP, success will be assessed on the basis of performance standards established by the ICT and described in Section 1 of this report. Nevertheless, discussion of William Mitsch's (Mitsch and Wilson 1996) theory of self-design is warranted here because it is relevant to site design, and especially to those parts of site design related to site topography and planting strategies.

Attitudes about wetland creation can be categorized along a continuum. At one end of this continuum is the "designer" approach, in which sites are planned, constructed, planted, and maintained as static systems, intended to duplicate a particular initial vision. At the other end of this continuum is the "self-design" or "self-organizational" approach, in which initial conditions are established at a site and sites evolve over time in response to natural colonization by plants, erosion and deposition of material, and other events. The designer approach can be likened to gardening or landscaping, while the self-organizational approach can be likened to old field succession (i.e., development of a forest in an abandoned pasture). In reality, most wetland restoration and creation projects adopt an attitude that is somewhere between the designer and the self-organizational approach, and the marsh creation projects that are part of the 50-year DMMP are no exception.

How do these theoretical approaches or attitudes translate to practical matters? If the 50-year DMMP projects strictly follow the designer approach, sites would be created so that a stable topography was present before planting was undertaken, and plant species would be allocated across the created sites in zones believed to provide suitable conditions for these plant species. Detailed site designs, including vegetation communities, would be designed on paper before site construction, and considerable effort would be expended in matching actual site conditions to detailed designs, including activities such as post-compaction contouring, planting, and excavation of tidal channels and pools. On the other hand, if the 50-year DMMP projects strictly follow the self-organizational approach, designs would call for little more than placement of dredged material at an elevation approximating that of nearby natural salt marshes. No detailed site designs would be prepared, and site characteristics would develop on their own, including characteristics such as contours and plant community structure. Along the Texas coast, including the project area, there are numerous examples of old dredged material sites that were not planned as wetlands but that are at least superficially similar to natural wetlands. The existence of these sites suggests that it is possible and even likely that reliance on a self-organizational approach will result in at least some marshes that are similar to natural marshes, but development may take years or decades and not all sites will develop to be similar to natural marshes. Furthermore, even though some old dredged material sites appear to be similar to natural marshes, development of specific features, such as tidal creeks, tidal pools, and irregular marsh edges (rather than straight marsh edges), seldom occurs.

By following a path that is somewhere between the designer approach and the self-organizational approach, the chance of meeting performance standards without incurring unnecessary costs is maximized. With this in mind, there will be no detailed site plans indicating the exact locations of tidal creeks, depressions, and vegetation community boundaries. Instead, plans will show:

- a general site outline (corresponding in part to earthen dikes or other structures required to confine dredged material);
- approximate boundaries and elevations of two plant communities, a relatively low-lying Spartina alterniflora monoculture, and a high marsh community consisting of a mix of *Batis maritima*, *Borrichia*

frutescens, Distichlis spicata, Lycium carolinanum, Monanthochloe littoralis, and *Salicornia virginica* (additional species, such as *Spartina patens* and *Paspalum distichum*, may be used to stabilize earthen dikes);

- guidelines for planting;
- an overlay of an aerial photograph of a nearby natural marsh, showing the general distribution of tidal creeks, depressions, and vegetation boundaries, but with the understanding that actual tidal creeks and depressions will follow contours that result from differential settling and erosion of dredged material with limited or no post-placement contouring, and that actual vegetation community boundaries will develop and change over time in response to environmental conditions and ecological interactions (i.e., factors similar to those that affect vegetation community development in natural marshes);
- temporary physical structures (including elevations) required for confinement of dredged material (such as earthen dikes) and an approximate time line for contouring of confinement structures to the level of the marsh; and
- permanent physical structures (including elevations) needed for protection from wave energy.

Adaptive Management

Adaptive management is a form of natural resource management that is responsive to ongoing developments and that is not locked into a pre-established plan. Although the phrase "adaptive management" is somewhat new, adaptive management is a common sense approach that has been practiced throughout history by farmers, business managers, and others who have to make decisions on the basis of incomplete information in a dynamic environment. Although wetland creation undertaken as part of the 50-year DMMP is driven by the goals and objectives established during the 3-4 November 1998 ICT meeting, these goals and objectives may be changed in response to various develpments. As noted in Section 1 of this report:

> ". . . Table 3 [the table of goals, objectives, performance standards, monitoring methods, and remedial actions] should be revisited periodically by the ICT as the DMMP is implemented. Problems with project design, changes in technology, changes in the perceived desirable characteristics of created wetlands, or other developments may arise that will render some or all of the information in Table 3 obsolete. However, revision of goals, objectives, performance standards, monitoring methods, and remedial actions should not be taken lightly. Experience has shown that people can lose sight of guidelines midway through projects or after projects are completed, and that periodic review of guidelines can prevent wasted effort and contentious claims of success or failure. ICT members agreed that changes to goals, objectives, performance standards, monitoring methods, and remedial actions should be specifically approved by the ICT."

Goals, objectives, performance standards, monitoring methods, and remedial actions recorded in Table 3, along with conceptual and detailed designs presented in this report, will guide management of this project, but with the concurrence of the ICT this guidance can be altered as needed to adapt to new information or perceptions.

Planting

This section provides a discussion of the rationale used to develop the suggested planting scheme, as well as a text box summarizing planting guidelines.

Salt marsh plants frequently colonize dredged material islands without active planting. Even when planting is undertaken, natural recruitment subsidizes planting efforts, leading to increased densities of vegetation, introduction of species that were not intentionally planted, and possibly increased genetic diversity. However, active planting programs are generally believed to accelerate development of plant communities similar to those that occur in natural salt marshes. This is especially true for sites that may be isolated or partly isolated from sources of seeds, such as sites surrounded by earthen dikes designed to confine dredged material. Also, active planting may prevent a single species from becoming established and excluding other species for an indefinite period, a phenomenon described in initial floristics theory (Egler 1954). Within the 50-year DMMP salt marsh creation program, there is scope for experimental trials of natural recruitment, but in general plans should include establishment of plant communities through a planting program.

Planting Methods

The U.S. Army Corps of Engineers and others have experimented with many salt marsh planting methods, including use of seeds, use of sprigs (individual plants or parts of plants, including root stock and stems, grown in nurseries or harvested from donor marshes), use of plugs (cores of plant and soil material, both transplanted directly from a donor marsh to the created site and transplanted from a donor marsh to a nursery before being transplanted to the created site), and use of containerized plants grown in nurseries. Most experimental work has focused on *Spartina alterniflora* plantings, but *Spartina patens, Batis maritima, Borrichia frutescens, Distichlis spicata, Lycium carolinanum, Monanthochloe littoralis*, and *Salicornia virginica* have all been established on dredged material and limited experimental data are available for some of these species.

Seeding: Sowing seeds of *Spartina alterniflora* has led to mixed success. Although sowing of seeds has been shown to be the most economical approach for establishment of *Spartina alterniflora* under some conditions (Woodhouse 1979), in areas subjected to frequent flooding by tides (that is, the lowest vegetated elevations of *Spartina alterniflora* marshes) seeds appear to wash away before plants take root. At slightly higher elevations, seeding has been more successful (see, for example, Webb et al. 1984 for an example from Bolivar Peninsula, in Galveston Bay, Texas). However, on the 50-year DMMP sites, active establishment of *Spartina alterniflora* will focus primarily on low areas along the edges of dredged material sites; most areas with slightly higher elevations, where seeding has been more successful, will be planted with high marsh species. The only exception to this may be around the edges of depressions that occur at higher elevations and that hold water trapped during extreme high tides or that hold rain water; these depressions are known to support *Spartina alterniflora* on natural salt marshes in the area, and it may be useful to seed some of these areas with *Spartina*

Planting Guidelines Summary

1. The most certain route to successful establishment of the targeted plant community is through transplanting of sprigs, harvested from nearby donor marshes. Sprigs should be transplanted to 1-m centers. *Spartina alterniflora* should be planted at the lowest vegetated elevations and around depressions that retain tidal water at relatively high elevations, while a mix of high marsh species (*Batis maritima, Borrichia frutescens, Distichlis spicata, Lycium carolinanum, Monanthochloe littoralis*, and *Salicornia virginica*) should be planted at higher elevations. Elevations for these two "zones" should be determined by surveying plant elevations at natural reference wetlands occurring close to each 50-year DMMP site. Natural reference wetlands should also have tidal exposure similar to that of the planned 50-year DMMP site. As noted elsewhere in this report, the same species can occur across a wide range of elevations in the project area, but this range decreases when individual sites are considered. Therefore, cost-effective planting will require knowledge of plant species elevation ranges under conditions found at nearby natural reference wetlands with exposure similar to that of the site being planted. To use this information effectively, elevations of the dredged material sites and nearby natural reference sites will have to be known with reasonable precision (at least ± 5 cm). Once a benchmark is established at dredged material sites, a laser level can be used to insure that elevations and species are appropriately matched. Species mixes should be determined based on species mixes at a nearby natural reference marsh. To the degree possible, the combination of species mix and elevations at the nearby natural reference marsh should be duplicated at the dredged material site. Follow-up monitoring should be used to determine if all species survive and spread after transplanting at similar rates. Species mixes should be adjusted to account for differential survival and spread. Species mixes should not be determined based on species availability at the donor marsh.

2. Dramatic cost savings can be realized if plant spacings can be reduced from 1-m centers to 2-m centers or greater. It will be useful to undertake trials on the first sites to be planted to determine if spacing can be increased from 1-m centers without dramatically altering plant community density or structure after two years of growth. Standard agricultural experimental designs (ANOVA designs) should be used to test the effect of spacing.

3. Cost savings can be increased further if plants can be established from seeds. It will be useful to undertake trials on the first sites to be planted to determine if seeding can be used successfully to establish plant communities. Standard agricultural designs (ANOVA) designs should be used to test the viability of seeding. Results of hydroseeding and aerial broadcast seeding (if space is available for reasonably large plots) should be compared to establishment via transplanting.

alterniflora.

Spartina patens can be established by sowing seeds provided that the area to be seeded will not be flooded by high tides before plants can establish roots (Webb et al. 1984). However, storm events or sustained winds can drive tidal levels to high marsh elevations, where *Spartina patens* is found, during any time of the year at the 50-year DMMP sites (see Figure 5). With this in mind, it would not be prudent to rely exclusively on sowing seeds as a method of establishing *Spartina patens*.

For high marsh species other than *Spartina patens*, (*Batis maritima*, *Borrichia frutescens*, *Distichlis spicata*, *Lycium carolinanum*, *Monanthochloe littoralis*, and *Salicornia virginica*), experimental seeding could be considered, especially if costs of planting plugs or sprigs is prohibitive. Seeding appears to be a common means of natural establishment for *Batis maritima* in the project area. However, because seeding is not routinely used for high marsh species, it should be undertaken experimentally, with the understanding that planting of plugs or sprigs may be needed if seeding fails. Also, it should be noted that seeding is not likely to succeed because of the combination of typical weather conditions and tidal levels in the project area: seeds need moisture to germinate and survive, so seeding is most likely to succeed during periods of reasonably high rainfall, but periods of reasonably high rainfall in the project area coincide with high tide levels, which would wash seeds away. With all of these points in mind, large-scale experimental seeding should not be undertaken unless small-scale experimental seeding indicates that success is possible.

Several methods of seeding are possible, including hydroseeding, broadcast seeding, mechanical direct seeding, and hand direct seeding:

- Hydroseeding is spreading of seeds in a slurry. Fertilizer and mulch can be added to the slurry. Stabilizers or binders that protect the soil surface from erosion and bind the seed to the sediment surface can also be added to slurries. Hydroseeding can be accomplished from boats (including airboats) or from equipment stationed on dikes, and is frequently used to vegetate sites where access is difficult, as will be the case on the soft sediments that will be characteristic of the 50-year DMMP sites. Adding mulch to the slurry at a rate of 5.5 kg/ha or more may result in improved moisture retention across the site, and therefore lead to improved germination and survival. However, if the site is inundated by high water before seedlings are well established, both mulch and seedlings are likely to be washed away.
- Broadcast seeding is the spreading of dry seeds over the soil surface. Broadcast seeding is sometimes followed by mechanical rolling or other methods intended to increase contact between soils and seeds. Seeds can be broadcast from tractor-mounted seeders, from aircraft, or by hand. Use of tractor-mounted seeders will probably not be practical at the 50-year DMMP sites because sediments will probably not support the weight of a tractor. Aerial seeding may offer a viable alternative, depending on costs. However, aerial seeding will result in seeds having poor contact with sediments,

which may reduce germination and survival rates. Broadcast handseeding is probably of limited usefulness because of labor costs and site size; however, broadcast handseeding may be useful in specific areas and situations, such as around depressions at higher elevations where patches of *Spartina alterniflora* are to be planted.

- Direct seeding is the placement of seeds directly on the site at specified locations and specified depths in the soil. In mechanical direct seeding, drills or modified planters (modified from planters used for soybeans, corn, or cotton) can be used. Drills would not be necessary or appropriate for the soft dredged material that will comprise the 50-year DMMP sites. Mechanical direct seeding with modified planters is probably not a good option for the 50-year DMMP sites for at least two reasons. First, soft sediments may make access with equipment difficult or impossible. Second, a species mix will be used on the site, and modified planters may not function well with seeds of different sizes and shapes (seeds could be separated in the planter, leading to an undesirable patchiness of vegetation).
- Direct hand seeding is placement of seeds directly into the soil at the desired depth. Unlike broadcast seeding by hand, direct seeding by hand increases the contact between seed and soil and does not require follow-up rolling or other approaches to increase contact between seeds and soil. However, it is labor intensive, and probably does not offer enough cost reduction relative to use of plugs to justify the increased risk of failure.

If seeding is used, it should be noted that pregermination requirements must be met to increase seed viability. Falco and Cali (1977) summarize pregermination requirements for *Spartina alterniflora* and *Spartina patens*. Pregermination requirements for other species are poorly known. Also, it should be noted that seed availability is unknown for high marsh species, but that it is unlikely that viable seeds for all species would be available at the same time during the year. Unavailability of all seeds at the same time will add to logistical difficulties and costs of seeding.

Because little is known about pregermination requirements or seed viability, high densities of seeds should be used with any of the methods discussed above. A reasonable starting point for seed densities is 200 seeds per square meter. This density can be adjusted based on the results of experimental seeding, if experimental seeding is undertaken. Assuming that germination and survival rates are similar for all species, relative numbers of seeds for different species should be based on relative areal cover of species found on nearby reference marshes. However, it is unlikely that germination and survival rates are similar for all species, and results of experimental seeding, if it is undertaken, should be used to adjust species ratios in seed mixes.

Timing of seeding should coincide with optimal weather and tidal conditions. If experimental seeding is undertaken, seeds will have to be collected, treated for pregermination, and stored until optimal conditions are available. Appropriate storage methods for seeds of high marsh species are poorly known; experimental trials will be needed to determine appropriate storage methods.

In short, if seeding is used, it should be used experimentally with the understanding that it may result in total failure and a need for planting using some other method, such as transplanting of plugs or sprigs. Seeding methods with the greatest possibility of success, in terms of lowering planting costs and leading to rapid development of a salt marsh, are hydroseeding and aerial broadcast seeding. If seeding is seriously considered, experimental seeding should be undertaken using standard agricultural plot experimental designs comparing hydroseeding, aerial broadcast seeding, and other methods of plant establishment, as well as different seed densities.

Transplanting: Plants can be obtained as plugs by coring into existing marsh, and plugs can be separated into sprigs, or individual ramets (i.e., individual "plants"), from plugs. This approach was used with reasonable success at the Mitchell Energy marsh creation sites, as well as at Sites 127a and 128 (personnal communication, Tom Stehn and Charles Belaire). Plants obtained from sandy substrates may be more easily separated than plants obtained from finer substrates. Plants should be collected from areas similar (in terms of tidal and salinity ranges) to the planned created marsh. After collection, plants should be kept moist and replanted within 24 hours of collection.

Past experience suggests that a substantial number of plants can be collected from donor marshes without causing long-term damage to donor marshes (personal communication, Tom Stehn and Charles Belaire). Nevertheless, the effect of plant collection on the donor marsh should be closely monitored, and collection methods should be altered or abandoned if donor marsh recovery is slow. ICT members and land managers should be consulted regarding the acceptability of collection of plants and recovery rates of donor marshes.

Previous plantings in the project area have relied on densities of one plant per m^2 (personal communication, Charles Belaire), or 4,047 plants per acre. Spread by rhizomatous growth and establishment of plants by naturally occurring seeding generally fills in sites planted at this density within 2 years or less under normal conditions. Unusual conditions, such as sustained drought, can increase the time needed for complete vegetation of sites or lead to a need for replanting. Planting in densities of one plant per m^2 has become common practice for high marsh species at other sites in U.S. coastal waters. However, experimental plantings undertaken at different densities suggest that it may be possible to rely on lower planting densities. For example, planting trials at Atkinson Island, in Galveston Bay, Texas, led to the suggestion that planting of *Spartina alterniflora* on 11-m centers was more cost effective than other planting densities, including 0.9-, 1.8-, 3.6-, and 7.3-m centers. In all cases, 60% cover was attained by the end of the second growing season (White et al. 1998). It should be noted that the Atkinson Island setting offered good conditions for establishment of plants by seed, because it was protected from tidal flooding and is in an area that often receives sufficient rainfall for seedling establishment. Thus, at least part of the reason for successful establishment after two growing seasons with widely spaced planting can be attributed to seeds germinating on bare ground between transplants.

No attempt has been made to test lower densities of planting in the vicinity of the 50-year DMMP sites or with the high marsh species that will make up most of the planting effort at the 50-year DMMP sites. Because considerable cost savings could be realized if lower planting densities are successful, experimental trials of lower densities may be justified in the 50-year DMMP sites. For example, reduction of planting densities from 1-m centers to 2-m centers would result in a 75% reduction in the number of plants required, leading to dramatically lower costs and lower impacts to donor marshes. If experimental planting is undertaken, standard agricultural plot experimental designs should be used to compare different densities.

Timing of planting can be critical to successful establishment of a salt marsh plant community. Optimal timing for planting of plugs or sprigs appears to be in early autumn, just before the onset of autumn high water (personal communication, Charles Belaire). However, planting should not be undertaken while the marsh surface is under water. Also, planting should not be undertaken during periods of drought, because survival of planted stock will be low. Lastly, planting should not be undertaken until dredged material has dewatered for several months. In general, it should be possible to plant sites within six months of dredged material placement. Within these constraints, timing of planting should be flexible enough to provide planting contractors with the opportunity to use their professional judgement and to work within logistical constraints.

Genetic Integrity of Planted Stock

A number of U.S. Army Corps of Engineers Districts have guidelines that limit use of seeds and transplant stock from areas beyond a prescribed radius from the restoration site. This radius is usually set at between 50 and 200 miles. These guidelines are intended to insure that the genetic integrity of planted sites is similar to that of nearby natural sites. That is, these guidelines are intended to prevent introduction of individual plants that are genetically distinct from local plants. There are no research results to support use of a specific radius for any plant species. However, current research using amplified fragment length polymorphism (AFLP) technology (a method of looking at DNA signatures) indicates that sites planted with imported *Spartina alterniflora* maintain a unique DNA signature for at least several years following planting (Streever, unpublished data). Anecdotal information and a number of published scientific papers suggest that genetically distinct *Spartina alterniflora* plants respond differently to various environmental conditions.

Little information is available for plant species other than *Spartina alterniflora*, but basic principles of population genetics suggest that concerns regarding regional genetic integrity should apply to high marsh species.

In many created wetland sites, plant stock is imported from outside the immediate project area, primarily because plant suppliers cannot provide local stock. For example, a dredged material wetland in Mobile, Alabama, was planted with stock from Virginia. Furthermore, a number of sites in Texas, and particularly around Galveston Bay, have been planted with the Vermillion strain of *Spartina alterniflora* (for example, the Atkinson Island demonstration project and parts of the Bayland Marina site in Galveston Bay are planted with *Spartina alterniflora*). The Vermillion strain of *Spartina alterniflora* was originally harvested in Louisiana and is now available from nurseries in Texas. Proponents of the use of Vermillion strain *Spartina alterniflora* believe that it is resistant to infections that sometimes plague stands of *Spartina alterniflora* and that it grows more quickly than most other *Spartina alterniflora*. However, no data are available on belowground (root mat) growth of Vermillion strain *Spartina alterniflora*, and no comparative data are available on the performance of Vermillion strain *Spartina alterniflora* under various environmental conditions. With all of this in mind, it would not be prudent to use Vermillion strain *alterniflora* on the 50-year DMMP sites. If Vermillion strain *Spartina alterniflora* is used, it should be used experimentally. Follow-up measurements of experimental planting should include assessments of belowground biomass measurements, since root mats protect dredged material marshes from erosion.

Guidelines for planting of 50-year DMMP sites that are presented in this report call for use of transplants or seeds collected near the planned 50-year DMMP sites (see text box "Planting Guidelines Summary"). If these guidelines are followed, there is little risk of establishing sites with compromised genetic integrity. However, if planting is undertaken using other approaches, issues related to genetic integrity should be considered.

Soil Nutrient Conditions and Fertilizers

Past marsh creation at Sites 127a and 128 and the Mitchell Energy sites have resulted in successful establishment of vegetation on a variety of dredged material substrates, including maintenance dredged material, in the vicinity of the planned 50-year DMMP sites. These successes suggest that planting will be possible on dredged material in the project area, and that soil testing may not be necessary. However, inexpensive soil testing for macronutrients (phosphorus, nitrogen, and potassium) and other soil conditions (pH, salinity) is available. Soil testing may identify suboptimal conditions in specific areas that could be rectified through addition of soil amendments or fertilizers. Soil testing should be considered for all areas, and should be used in areas where plant establishment fails.

A number of researchers have assessed the use of fertilizers in dredged material wetland planting (see, for example, Woodhouse et al. 1972, Garbisch et al. 1975, Webb et al. 1984). Some results suggest that fertilizer can increase growth rates, but there is no evidence that suggests a need for fertilizers. That is, fertilizer may lead to more rapid plant growth, but plants grew on dredged material with or without fertilizer. Also, at least one fertilizer trial appeared to result in plant stress (Webb et al. 1984). With this information in mind, fertilizer should not be routinely used as part of the 50-year DMMP planting program. However, experimental fertilizer trials may be warranted, especially in areas with poor plant growth. Also, if soil tests indicate deficiencies in macronutrients, use of fertilizers should be considered.

References

Bertness, M.D. and A.M. Ellison. 1987. Determinants of pattern in a New England salt marsh plant community. *Ecological Monographs* 57: 129-147.

Bertness, M.D., C. Wise, and A.M. Ellison. 1987. Consumer pressure and seed set in a salt marsh perennial plant community. *Oecologia (Berlin)* 71: 190-200.

Cahoon, D.R. and J.C. Lynch. 1997. Vertical accretion and shallow subsidence in a mangrove forest of southwestern Florida, U.S.A. *Mangroves and Salt marshes* 1: 173-186.

Darnell, T.M., E.H. Smith, J.W. Tunnell, Jr., K. Withers, and E.R. Jones. 1997. The Influence of Landscape Features on Bird Use of Marsh Habitat Created for Whooping Cranes (*Grus americana*) through Beneficial Use of Dredged Material: Final Report. Texas A&M University, Center for Coastal Studies, Corpus Christi, Texas.

Ecological Data Consultants, Inc. 1994. The Community Analysis System 5.0. Ecological Data Consultants, Inc. P.O. Box 760, Archer, Florida.

Egler, F.E. 1954. Vegetation science concepts. I. Initial floristic composition: a factor in old-field vegetation development. *Vegetatio* 4: 412-417.

Garbisch, E.W., P.B. Woller, and R.J. McCallum. 1975. Satl marsh establishment and development. U.S. Army Corps of Engineers, Coastal Engineering Research Center. TM-52.

Godfrey, R.K. and J.W. Wooten. 1981. Aquatic and Wetland Plants of Southeastern United States. The University of Georgia Press, Athens, Georgia.

Gosselink, J.G. 1984. The Ecology of Delta Marshes of Coastal Louisiana: A Community Profile. U.S. Fish and Wildlife Service, Biological Services FWS/OBS-84/09. Washington, D.C.

Hurlbert, S.H. 1971. The non-concept of species diversity: a critique and alternative parameters. *Ecology* 52: 577-586.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54: 187-211.

Krebs, C.J. 1989. Ecological Methodology. HarperCollins Publishers, New York.

Kusler, J.A. and M.E. Kentula (eds.) 1990. Wetland Creation and Restoration; The Status of the Science. Island Press, Washington, D.C.

Landin, M.C., J.W. Webb, and P.L. Knutson. 1989. Long-term monitoring of eleven Corps of Engineers habitat development field sites built of dredged material, 1974-1987. Waterways Experiment Station Technical Report D-89-1, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

McKee, K.L. and W.H. Patrick. 1988. The relationship of smooth cordgrass (Spartina alterniflora) to tidal datums: A review. *Estuaries* 11: 143-151.

Rozas, L.P. and R.J. Zimmerman. 1994. Developing design parameters for constructing ecologically functional marshes using dredged material in Galveston Bay, Texas. In Dredging '94.

Proceedings of the 2nd International Conference on Dredging and Dredged Material Placement. Volume 1. American Society of Civil Engineers, New York. Pp. 810-822.

Southwood, T.R.E. 1978. Ecological Methods. University Press, Cambridge.

Streever, W.J. 1999. Examples of performance standards for wetland creation and restoration in Section 404 permits and an approach to developing performance standards. Wetlands Research Program Technical Notes. US Army Corps of Engineers Waterways Experiment Station. In press.

Streever, W.J. and A.J. Genders. 1997. The effect of improved tidal flushing and competitive interactions at the boundary between salt marsh and pasture. *Estuaries* 20: 804-815.

Streever, W.J. and S.A. Bloom. 1993. The self-similarity curve: a new method of determining the sampling effort required to characterize communities. *Journal of Freshwater Ecology* 8: 401-403.

Streever, W.J. and K.M. Portier. 1994. A computer program to assist with sampling design in the comparison of natural and constructed wetlands. *Wetlands* 14:199-205.

Taylor, K.L. and J.B. Grace. 1995. The effects of vertebrate herbivory on plant community structure in the coastal marshes of the Pearl River, Louisiana, USA. *Wetlands* 15: 68-73.

Washington, H.G. 1984. Diversity, biotic and similarity indices: a review with special relevance to aquatic ecosystems. *Water Resources* 18: 653-694.

Webb, J.W., J.D. Donn, B.H. Koerth, and A.T. Weichert. 1984. Seedling establishment of *Spartina alterniflora* and *Spartina patens* on dredged material in Texas. *Gulf Research Reports* 7: 325-329.

Wold, H. 1981. Similarity indices, sample size and diversity. Oecologica. 50: 296-302.

Woodhouse, W. W., E.D. Seneca, and S.W. Broome. 1972. Marsh building with dredged spoil in North Carolina. *N.C. Agricultural Experiment Station Bulletin* 445.

Woodhouse, W.W. 1979. Building salt marshes along the coast of the continental United States. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Sr-4.

Zedler, J.B., P. Nelson, and P. Adam. 1995. Plant community organization in New South Wales saltmarshes: Species mosaics and potential causes. *Wetlands (Australia)* 14: 1-18.

Gulf Intracoastal Waterway
Aransas National Wildlife Refuge
Dredged Material Management Plan

Appendix B

General Design and Construction Considerations for Marsh Sites

GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS

Elevations and Topography (Plant Community Establishment).

The proper hydrology and salinity ranges of each wetland creation site are critical for establishing a specified plant community or habitat. These two parameters are hard to control as rainfall and high evaporation and evapotranspiration rates influence salinity and rainfall and water level fluctuations influence hydrology. As surrogates to establishing hydrology and salinity regimes, elevation and topography of the wetland surface are used. Elevation and topography in the created marshes should be made reasonably mimic the natural marshes with the expectation that the hydrology and salinity will then be similar.

Elevation may be the most obvious physical parameter influencing vegetation communities, but topography clearly has a role. Two locations can have identical elevations, but if one location is partially blocked from tidal exchange by surrounding high ground or by distance from a tidal source, the resulting vegetation community is likely to be adapted to more severe fluctuations in salinity during the year. In general, the partially blocked sites will support proportionately more species with a tolerance for high salinities, since evapotranspiration coupled with irregular tidal flushing can lead to hypersaline conditions; low salinity will not kill these plants, but in periods of high sustained rainfall ("wet years") plants with little tolerance for saline conditions may compete with and slowly replace these plants. Conversely, in sites that have good tidal exchange plants adapted to cope with mid-range salinities, such as *Spartina alterniflora*, may dominate the plant community. As an example of the possible effect of topography, Figure 1 shows the elevations at which *S. alterniflora* is found at across several surveyed areas in the ANWR region. The figure also shows the much smaller range at which *S. alterniflora* exists at a single site.

Achieving specified elevations and topographic characteristics during the placement of dredged material is difficult. The difficulties come from three sources. First, the dredged material will slope downward from the location of the dredge discharge pipe to the placement-area effluent structure. Depending on the characteristics of the dredged material the slope may be very mild or relatively steep. Surveys of the ANWR demonstration site PA 128 showed that the fine material in that site created a 150 ft - 200 ft wide, virtually-flat berm near the discharge pipe. The material was most coarse at this location. The slope toward the effluenct structure was very mild though some local slopes in the coarser material were 1:20 (Figure 2). Therefore, if discharging from only one location, achieving specified elevations in the site or forming ponds and channels in the placed dredged material over large areas is not feasible. Techniques for enhancing elevation and topography, such as moving the dredge pipe or earthwork before or after placement may be necessary and discussed below.

The second difficulty in achieving specified final marsh elevations and topography is natural consolidation of the dredged material. All dredged material will bulk to a higher volume as it is dredged and placed due to entrainment of water between sediment particles. After placement, the material consolidates under its own weight or possible overburden. If the dredged material is sand, bulking and post-placement consolidation happen quickly and can be neglected. However, fine-grained material will consolidate slowly requiring several months to several years. In some cases, particularly where little of the material is subaerial, complete consolidation of the material never occurs. The amount the material will bulk and the amount of consolidation that will occur are generally unknown and must be evaluated on a case-by-case basis. Laboratory tests can be used to estimate consolidation of the material. The tests can take several months to complete. Laboratory tests of the existing channel sediments are underway at the US Army Engineer Research and Develop Center and should provide insights into the bulking and consolidation characteristics for the dredged material. The results will be published under separate cover. Another factor influencing consolidation is that as the material is discharged into the placement area, the coarser material settles nearest the discharge pipe, while the finer materials travel further away. Therefore, one would expect both a variation in the slope of the material and the consolidation rate across the placement area. The influence of grain-size sorting across the placement area on consolidation of the material cannot be effectively duplicated in laboratory tests, or analytical or empirical models.

The third difficulty in achieving specified elevations and topography in a created marsh, is that the underlying foundation material may consolidate under the weight of the overlying dredged material. Because the nature of the foundation material may vary over the project area, some differences in settling caused by differences in foundation material may occur.

Dredged Material Placement Techniques and Adaptive Management for Modifications

The natural marshes in a given area have considerable variation in topography (though over a small elevation range). Creating the topographic structure in the same detail will be difficult with newly placed dredged material. However, at some level of detail achieving elevations and topography is feasible both technically and economically, though the possible techniques are not well developed. It is recommended that the best attempt (technically and economically) be made to achieve target elevation ranges and topographic characteristics *during* the dredged material placement process. The sites should then be allowed to consolidate and develop vegetation communities. Following this period, an evaluation of the sites should be made to determine if additional work is necessary to develop the site.

The following paragraphs describe briefly possible approaches to achieve elevations and topography at the sites.

Pre-Placement Contouring of Seabed

The bed of the placement area can be contoured prior to placement of the dredged material with the intent that the surface of the dredged material will roughly reflect the underlying bathymetry. Surveys of PA 127A indicate that where pre-placement holes were dug in the placement site, the surface of the overlying dredged material exhibited a topographic depression. Similar behavior can be observed in confined placement areas where dewatering trenches in underlying lifts of dredged material are reflected in the surface depressions in the most recent lift of dredged material. Therefore, it is possible to dig trenches, holes, or build mounds on the bed of the placement site prior to placement resulting in shallow channels, ponds, and berms respectively in the surface of the dredged material after placement. Careful study of the consolidation behavior of the dredged material will be necessary to estimate the amount of differential consolidation between areas.

Moving Dredged-Material Discharge Pipe

The dredge discharge pipe should be moved as often as necessary to create as much of the proposed marsh surface as possible. Moving the dredge pipe may not be sufficient to create all of the features desired, but it can create the base topography upon which more detailed features can be constructed. Moving the discharge pipe around the site will create larger areas of similar elevation, avoid long slopes in one direction, and avoid steep slip faces (particularly in sandy material). As the mounds created beneath the discharge pipe merge with one another, more varied topographic features will develop with the possibility of increased edge:area ratios.

The distance that the dredge pipe must be moved depends on the characteristics of the dredged material. Coarser material creates steeper mounds with smaller crowns. Finer material creates broader, wider mounds. (Compare Figures 3a and 3b.) The discharge pipe can therefore be move further each time when fine-grained material is being placed.

Repositioning the discharge pipe can be costly to the project if dredging has to be stopped to move the discharge pipe. If possible, the dredger should use one or more Y-connectors in the discharge line such that there would be at least two discharge points in a cell. Only one or two of the discharge lines would be used at a time. While one line is discharging, another would be repositioned. In this way, the dredge is not idle while the discharge pipes are moved. A flexible discharge pipe, such as high-density polyethylene pipe, should be considered as it may be relatively easy for a crane to drag it across the site as needed.

Thin-Layer, Multiple-Lift Placement

Another approach to achieve specified elevation and topographic characteristics is to place material in multiple lifts. The first lift is placed more quickly but with moderate care in an attempt to achieve the target elevation. The site is then left to consolidate, vegetate, and develop in any other way. During the next dredging cycle, if the site is too low or does not have the topographic characteristics desired, then another thin lift of material is applied to the site with the discharge pipe moved about as necessary to achieve desired features. If necessary and if feasible, certain dredged material characteristics might be specified to help achieve the final design. For example, a more or less sandy material might be specified if more or less mounding is needed, respectively. Members of the ICT noted that a thick stand of smooth cordgrass has been shown to prevent the accumulation of dredged material within the stand during subsequent placements. This may be a detriment or a benefit to a multiple-lift approach depending on the desired outcome for the site. A stand of cordgrass could create a depression in an otherwise higher elevation marsh by preventing sedimentation in certain areas.

Dredged Material Spray Discharge

A recent, technique for achieving small variations in topography, is the use of ~~dredge~~ ~~material~~ spray discharge. The ~~dredged~~ ~~material~~ spray discharge has been applied to several projects. The material is sprayed up to 150 ft from a nozzle mounted on the deck of the barge. The spray of material is swept back and forth as necessary to create the desired topography. The possible limitation for the DMMP sites is the short spray distance. Many of the DMMP sites are 1000 ft by 3000 ft. Hence, if the dredge works around the outside of the site, the spray distance (150 ft) would reach at most only 15 % of the way into the site from the perimeter. Most of the interior of the site could not be reached with the spray. If the nozzle can be placed on the end of a long discharge line, then it may be possible to reach the interior.

Interior Dikes & Surface Features

During the construction of containment structures around the perimeter of a wetland creation site, interior dikes can be constructed which would control the movement of dredged material through the site causing material to settle in some areas and not in others. Broad topographic or elevation changes can be controlled in this way. Other features could be created prior to placement to add topographic relief to the site such as islands or ring dikes. Additionally, once the dredged material has filled the site to a specified level (a base elevation upon which small topographic features are built), small surface features such as water filled tubes, hay bails, and earthen berms might be positioned to direct flows into or away from specified areas.

Interior dikes are commonly use in contained placement facilities to enhance settling. The dikes direct the dredged material inflow circuitously through the placement area forcing water to remain in the facility longer before reaching the outflow structure. The volume of sediment that settles in the facility is increased. However, using the dikes in more complicated designs and to control the final surface elevation of a site is less common. The use of dikes to direct the material across the site in the final stages of placement is untested and it should be expected that modifications to the approach will be necessary.

Post-Consolidation Contouring

After the material has been placed and has been given a specified amount of time to consolidate, equipment could be brought back to the site to contour the surface. In general, the material should be at the target elevations for the site. The equipment would then add small topographic features such as ponds, channels, and low, broad ridges. The difficulty will be finding equipment that can reach the interior of the sites. Heavy equipment will not be able to traverse the site even after initial consolidation. The material will still be too weak to support the loads. Careful use of drag-lines or similar equipment might be successful.

Using Decomposable Materials and Water Flows

Where depressions such as channels and ponds are desired, decomposable materials such as hay bails could be placed prior to or during certain stages of dredging. As the material decomposes, it will leave a depression in the dredged material surface. Alternatively, water could be pumped to locations where depressions are desired. The flow of water would likely create a depression at the discharge point and depending on the conditions at the site, the flowing water would create "natural" channels across the marsh surface. These approaches are untested and may require modification or specialized equipment as we learn.

Geomorphology and Site Configuration.

The configuration of sites relative to surrounding natural features must be considered. Attempts should be made to blend new marshes with existing marine habitats and land forms. Features at the boundaries of projects must be considered, such that construction of a site does not cause adverse conditions in adjacent areas. The interactions between existing natural channels, holes, or shoals and the project should be considered. As an example, flows through an adjacent channel or cut could undermine a project structure, and blocking an existing channel or cut could have implications for off-site biological communities. The flow of rainwater (either as surface water or ground water) from a newly constructed site into or onto an adjacent site should not be allowed to result in a change to the adjacent habitat.

Ecological and Physical Barriers.

In the design of each site, ecological and physical barriers should be avoided, and opportunities for ingress and egress should be maximized. For example, sufficient openings should exist within and between structures to allow fish into the site. The length of the interface (or edge) between marsh vegetation and open water should be maximized. Tidal flow, wave inundation, or rainfall runoff from the sites should not be limited beyond that desired. In some cases, it may be desirable to design sites so that water flow across the site *is* limited to create hypersaline and periodically brackish conditions that are found in some areas of the natural marshes.

Variation from the 300-ft Buffer.

A 300-ft buffer between existing land and the DMMP wetland creation sites was suggested for all sites in the Section 216 Feasibility Study. Deviation from a strictly enforced 300-ft buffer is recommended to create constrictions as well as wide pools. In the general designs for the sites discussed in the next section, recommended increases or decreases in the buffer in certain areas are shown.

Structure Functionality and Integrity.

Two types of structures will be used at the DMMP wetland creation sites. One structure is for erosion control while the other is for containment of the dredged material. The crest elevation of the erosion protection structure depends on the characteristics of the site, both the exposure to waves and the design of the marsh. The type of structure is selected for stability in the given wave and current environment, and designed to avoid possible toe, overtopping, and flanking erosion. The containment structures must be sufficient to contain the dredged material without failure. The existing beneficial uses projects in the ANWR region are reviewed below to determine the success of the different structures installed. The DMMP sites are then related to the existing sites to help determine which structures would be adequate for the DMMP sites.

The containment-structure crest elevations will be more than twice the elevation of the erosion protection structures. During dredged-material placement, the dredged material will bulk and contain a greater volume than the *in situ* volume. The containment structure must account for bulking, as well as ponding to enhance settling of suspended sediments and freeboard to reduce the risk of overtopping. After the dredged material has consolidated, the elevation of containment structures can be graded down to make the site more suitable as habitat for certain species including whooping cranes which reportedly avoid areas with nearby high topographic features.

The strength of the foundations upon which the structures and dredged material will be placed have to be evaluated to ensure that structures will remain stable and that the structure and marsh surface will remain at the desired elevations. If the foundation is weak or unconsolidated, the foundation may consolidate or fail under the weight of material placed on it. Techniques to strengthen the foundations may be necessary.

Erosive Forces.

Exposure to wind- and boat-induced waves, and ambient and boat-induced currents need to be considered. Wind-waves will be of most concern and only the proposed DMMP sites C, G, and H are exposed to boat wake. Currents are important particularly around cuts between islands and other constrictions which may have a hydraulic gradient across them. Barge-induced currents along the GIWW may be a problem in a few locations where the marsh sites are near the waterway, particularly adjacent to cuts or constrictions. These areas are noted in the site descriptions and should be given careful attention prior to construction. Other currents, though not considered a primary concern, are generated by winds and tides.

Construction and Ease of Repair.

In the development of designs for the sites, construction techniques need to be selected that will minimize costs. Construction is difficult in these soft-bottom areas when heavy equipment is required. They often have to operate from a barge. The DMMP sites are shallow, making close-in access difficult. Therefore, how structures should be built must be given consideration. It would be prudent to consider future construction or repair methods, as well, in order to keep future costs to a minimum.

Public Education and Access.

If the District pursues the use of the projects as a public relations tool, public education and access to the some of the sites should be considered in the project designs.

Experimental Nature of the DMMP.

Many unknowns exist regarding the best approaches for dredged material placement, structure construction, characteristics of the dredged sediments, and the establishment of habitat and vegetative communities. The first cells constructed in the DMMP will therefore be experimental, in that they will help guide future construction of cells. The technology and approaches that are recommended for the DMMP sites were derived from the existing beneficial uses projects in the ANWR region. After monitoring the first DMMP cells (between dredging cycles), considerably more information will be available.

Section 404 Requirements.

Projects that discharge dredged or fill material in waters of the United States are regulated under Section 404 of the Clean Water Act. It would be prudent to contact regulatory staff in the District to clearly identify regulatory requirements pertinent to the 50-year DMMP. One of several issues to be considered is regulatory requirements in regard to wetlands created during early dredging cycles and impacted by later dredging cycles. Because of this project's potentially high profile, it is especially important to be in compliance with laws that protect wetlands and regulate activities that may impact wetlands.

EVALUATION OF EXISTING BENEFICIAL USES SITES (PA 127A, PA 128, MEC #1,2, & 3)

The designs of many if not all of the proposed DMMP sites are based on the successes of the existing demonstration sites constructed by the District and the Mitchell Energy Corporation sites in the vicinity of the ANWR. The section below is a review of those sites highlighting the characteristics that might be reproduced in the DMMP sites. Following the review of the existing sites, the conceptual designs for the DMMP projects are discussed.

Evaluation of Structures at Existing BUDM Sites (PA 127A, PA 128, MEC #1, #2, and #3)

Most of the wetland creation sites proposed for the DMMP will require structures to protect against wave-induced erosion. These structures add significantly to the cost of the projects. The 3,700 ft riprap breakwater at PA 127A cost about $500,000 in 1993. Payment was based on the weight of stone used. About 10,000 tons were used and cost about $50 / ton. Another example is the approximately 3,000 ft of geotextile tube at PA 128 where the purchase and installation cost was $170,000 in 1993. If the cross-sectional area or length of the structures can be reduced, the cost of the structure will be reduced. For a riprap structure, the cross-sectional area can be reduced by steepening the side slopes or reducing the crest height or both. In the case of the structure at 127A, the side slopes are nominally 1:2, which is as steep as is practical. Therefore, the crest elevation of the structure is the critical parameter for cost. For the geotextile tube, if a higher structure crest elevation is necessary, additional tubes or foundation work will be necessary which would increase the cost of the structure. So, in the design of the DMMP wetland creation sites, the lowest crest elevations possible should be sought to achieve the lowest costs. Additionally, low structures are more appealing both aesthetically and ecologically.

Structure heights must be sufficient to protect the developing wetlands from erosion, but it is not clear how much protection is necessary for wetlands. The Corps has excellent guidance for designing erosion protection structures, but the required design parameters for using that guidance in wetland design are unknown. The principle design parameters are the incident wave height, wave period, duration and frequency of occurrence and the value of those same parameters tolerable as transmitted beyond the structure. The incident wave parameter values can be derived for the DMMP sites based on wind and water level records and knowledge of the wind fetches to the sites. But the tolerable transmitted values are unknown for these and most wetlands. For example, it is not known whether a developing wetland can be exposed to 1 ft waves without damage. If it could withstand a 1 ft wave, under what conditions would that occur. That is, what duration or frequency of occurrence is acceptable? All this to say that experience with erosion protection structures for wetlands in a given area is more valuable than using existing general design guidance.

Existing wetland creation projects in and around the Aransas National Wildlife Refuge in Texas provide valuable information with regard to adequate structure height. Two of the projects were constructed by the District at PA 127A and PA 128. Three other projects were constructed by the Mitchell Energy Company (MEC) on the south side of Bludworth Island. As mentioned, a riprap breakwater was constructed at PA 127A (Figure 4) and a geotextile tube at PA 128 (Figure 5). The three MEC sites are protected by earthen dikes covered with a filter fabric and overlaid by an articulated concrete mattress (Figure 6). All of the District's and MEC structures have been successful in certain ways at protecting the created marsh from erosion. It is reasonable to use them, then, as design guidance for future projects that are exposed to similar environmental conditions, e.g similar orientation and wave conditions. Each site is therefore described below to help relate them to the proposed DMMP sites.

Description of the Breakwater at PA 127A

The breakwater at PA 127A has an average crest height of 3.2 ft MLT. Behind the breakwater is an earthen dike with a crest elevation between 4.0 - 5.0 ft MLT which was used to contain dredged material placed in the site. Between the breakwater and the dike is a 50 - 70 ft expanse of shallow, open water with bottom elevations between 0.0 and 1.5 ft MLT. Generally, the water is most shallow near the breakwater and deepens toward the dike. Smooth cordgrass is flourishing on the banks of the earthen dike where it was planted and appears to be slowly propagating down the slope of the dike. Figure 7 provides a good view of the breakwater, dike, open water and cordgrass. The higher elevations on the dike are vegetated, but there is evidence of an erosion scarp on the seaward side of the dike presumably due to waves that have been transmitted passed the breakwater during high wave and water level periods. The erosion, while present, is slow and as the stand of cordgrass expands, the rate of erosion will be slower yet.

A reasonable conclusion from this site is that the elevation of the breakwater crest is sufficient to protect a stand of cordgrass (and its substrate) which is expected to grow between 1.2 ft and 3.2 ft MLT. However, higher features behind the breakwater may be subject to erosion by waves transmitted passed the breakwater. The dike behind the breakwater is between 1 and 2 ft higher than the crest of the breakwater and is slowly eroding. In light of this observation, high elevation marshes created in the lee of a structure like the breakwater will need additional wave dissipation. Either a higher structure is necessary or a wider expanse of shallow water and low-marsh. From the observations in Figure 7, a 50 ft expanse of open water with an approximate stand of cordgrass less than 20 ft wide is not sufficient for complete protection.

Using shallow water and the erosion-protection function of low-marshes is a preferred approach to wave dissipation, rather than raising the elevation of the structures. The shallow water allows ingress and egress of organisms in the site and provides desirable marsh-edge habitat. The shallow water also dissipates wave energy as wave breaking is dictated by water depth. A rule-of-thumb is that waves break in water depths that are 80% of their height, e.g. a 1 ft wave will break in water that is about 0.8 ft deep. It is recommended though that the open-water bed slope upward from the breakwater to the marsh. This is a more natural condition. In the interest of optimizing the capacity of a given site and the extent of open water and low marsh, it is recommended that the open water buffer between erosion protection structures and earthen containment dikes be approximately 100 ft. An expanse of cordgrass is also necessary which may need to be greater than 20 ft as suggested above. Estimating a sufficient width is currently subjective and requires additional information. This should be an area of investigation during the development of the proposed wetland sites. It is likely that as the crest of the containment dikes are eroded to lower elevations, they will colonize with cordgrass.

The containment dike at the south end of PA 127A has no protection against waves from the south to the southwest. Yet, the earthen dike is still in good condition after 5 years. Some erosion has occurred similar to the erosion along the dike shown in Figure 7. That is, an erosion scarp is present and receding slowly. In the meantime, an ever widening stand of smooth cordgrass fronts the dike helping to dissipate waves. Knutson et al (1981) suggested that unprotected, developing wetlands, will be nearly 90 % successful if fetches are less than one mile and nearly 90 % unsuccessful for fetches greater than 10 miles. Many factors besides fetch effect the success of a site (e.g. winds, shoreline orientation, water depths, sediment characteristics, vegetation type and marsh elevation). However, fetch can probably be used is a strong indicator of success. Hence, it is not surprising to find successful cordgrass development at the south end of PA 127A. The wind fetches from the south to southwest are 2 - 4 miles, respectively, though they may be interrupted by shoals which help to keep wave growth down. The wind data from 1985-1990 (Table 2) suggest that winds from the south occur 12 % of the time and winds from the southwest 2 % of the time (and always less than 15 knots). This suggests that opportunities may exist in the proposed DMMP sites where minimal or no structural protection will be required for successful marsh development.

Description of the Structures at PA 128

Four geotextile tubes were used at PA 128. The different tubes are identified in the aerial photograph of Figure 8. Tube #1 faces the East-Northeast and has a crest elevation that generally slopes between 2.0 ft to 2.4 ft MLT. (The elevations reported herein for geotextile tubes were obtained from a June 1998 survey of the tube crest elevation provided by the District.) The surveys indicate a gradual slope of the tube crest, but also show the variability of the tube crest from point to point. The tube circumference is assumed to be 15 ft based on estimates from photographs and reports that both 15 ft and 22.5 ft circumference tubes were used at this site. The tube is about 3 ft high.

Portions of the fabric along Tube #1 tore and the elevation was steadily decreasing. The District repaired the structure by overlaying articulated concrete mats to restore the height. It is assumed (though unconfirmed) that the fabric tore after ultraviolet (UV) light degraded the strength of the fabric below existing normal-stress levels. No indication is present that any other mechanism such vandalism or debris-damage might have caused the ruptures.

Tubes #2a and #2b face the Southeast. These tubes are assumed to be 22.5 ft in circumference and are 3 ft - 3.5 ft high. The elevations along the crest of Tube #2a are about 2.0 ft MLT though they vary considerably ranging from as low as 1 ft MLT to 3 ft MLT. These tubes have torn in several places just as in Tube #1. It is believed that the lowest elevations in the surveys are located in the torn sections. A plot of the tube elevations suggests that initially Tube #2a was close to 2.0 ft MLT. Tube #2b is similar in dimension to #2a but has a crest elevation between 3.0 ft - 4.0 ft MLT. The variation in elevation from point to point along the crest of the tube is not as great as in Tube #2a. The bed elevation is higher beneath this tube accounting for much of the elevation difference.

Tube #3 faces the South-Southwest. It is believed that this tube is 15 ft in circumference. The height of this tube is 1.5 to 2.0 ft, but the crest elevation of the tube is roughly between 2.0 and 2.5 ft MLT because the bed elevation is higher than beneath the other tubes.

All of the tubes at PA 128 have satisfactorily protected low-elevation smooth cordgrass and open water areas. It is believed that review of the success of Tube #1 sufficiently describes the merits of all the tubes as Tube #1 is exposed to the longest fetches and predominant winds. Tube #1 is also on the low side of the tube elevations measured.

Tube #1 as identified in Figure 8 is a containment dike for the dredged material as well as erosion protection for the site. The crest elevation of the tube slopes gradually downward offshore. The end nearest the GIWW is at about elevation 2.4 ft MLT and the bayward end is at about elevation 2.0 ft MLT. The elevation along the length of the tube varies within this range.

The low marsh in the lee of this tube is a wide expanse of smooth cordgrass. The substrate elevations obtained from transect surveys across the marsh show the substrate to be between 1.5 ft and 2.0 ft MLT. The plants growing nearest the tube have shown no indication of loss due to erosion. The tube is shown in Figure 5 one and a half years after the cordgrass was planted. The vegetation was planted on 1 m centers in the late summer or fall of 1993 (Figure 9).

The wave exposure of this structure is similar to the exposure of the north end of the breakwater at PA 127A. The breaker is roughly 1 ft higher than the tube. Yet, the tube offers sufficient protection for a low-elevation marsh in its lee. For a low-elevation smooth-cordgrass marsh, a geotextile tube at the elevation of Tube #1 appears sufficient. Very few locations have exposures to waves as high as this site and 127A. Tube #1 has fetches from the Southeast (2 mile) to the Northeast (14 mile). Winds from this quadrant occur more than 60 % of the time, mostly from the southeast. Wave heights incident to this structure were estimated by ACES to be between 1.5 ft and 2.5 ft depending on water depth. (Fetch water depths for the calculations were considered between 6 ft and 9 ft.) One would expect that Tube #1 would not be able to protect a high feature such as an earthen containment dike unless a large stand of low-elevation cordgrass stood between the tube and the dike. Recall that the breakwater at PA 127A which was 1 ft higher than this tube was not able to fully protect the higher elevation earthen containment dike in its lee. (An investigation of the original island shoreline at PA 128 might indicate an upper limit on a necessary stand of cordgrass. If the island shoreline is not eroding we can judge that the shallow water and expanse of cordgrass found at this site constitutes a sufficient width.)

Discussion of the Structures at the MEC Sites.

Mitchell Energy Co., using dredged material, constructed three wetland creation sites adjacent to Bludworth Island as shown in Figure 10. The development of the sites was sequential with construction of the first site in 1991 and the last site in 1995. Each new site was physically connected to the previous site. However, they remain hydrologically separated as there is no apparent exchange of water between sites. Each site is well connected to the bay. A water buffer of about 200 ft was maintained between the first site and Bludworth Island and about 320 ft for the other sites. The intent of the water buffer was to allow for tidal connection to each site from the backside. Also, seagrasses were reportedly present prior to construction of the sites, and since construction, the seagrasses have continued to multiply creating valuable aquatic habitat.

The dike around each site was constructed by removing bottom sediment from inside the site and placing it in the dike. The seaward face of the earthen dike which faces almost due East was covered with filter fabric and overlaid with articulated concrete mattresses as shown in Figure 6. On the landward (Bludworth Island) side of the sites, no erosion protection is used since the exposure to erosive mechanisms is negligible. Based on survey data by Belaire Consulting, Inc., dated March 16, 1992, the dike around the first site (MEC #1) varied between 3 ft and 5 ft MLT. The unprotected dikes on the leeward side of the site range between 4.0 ft and 5.0 ft MLT, while on the bayward side they generally range between 3.5 ft and 4.0 ft MLT. The marsh surface immediately behind the bayward dike varied but was 3.5 ft - 4.0 ft MLT. Belaire Consulting noted that wave-induced erosion had occurred at points behind the bayward dike uprooting plants. They alleviated this problem by installing concrete bags along the crest of the dike where elevations were low. They added one to three layers of bags interconnected with vertically-driven steel reinforcing bar. Each bag added about 0.5 ft to the height of the dike. A view of the bags on the dike are shown in Figures 11a-c. The bags raised the elevation of the structure to an estimated 5.0 ft MLT. No erosion has been noted at this site since the bags were installed.

The dikes for the next two MEC sites (MEC #2 and #3) were higher than for MEC #1. No survey data is available, but the crests elevations are estimated to be 6.0 ft MLT. The dikes are shown in Figures 12 and 13. The elevation of the marsh inside MEC #2 was similar in appearance to MEC #1. Neither MEC #2 or #3 showed any signs of erosion inside the diked area, although MEC #3 was largely unvegetated when last observed.

Comparisons to Proposed DMMP Sites

The discussion of the existing sites above was intended to highlight the primary characteristics and successes of the structures in use in the region around the proposed DMMP sites. The successes are considered in the conceptual design of the proposed DMMP sites. Using proven erosion protection structures for wetlands in similar settings is more valuable than approximating designs with general design guidance.

Figure 14 shows the locations of the proposed DMMP wetland creation sites and the existing demonstration marshes along the GIWW at the ANWR. Table 1 relates the fetch-exposure between the sites. Table 2 provides the percent-occurrence of wind speed and direction in the region. Figures 15 contains a representative sample of water levels for the area taken in 1996. The elevations of the structures are overlaid on the plot (except for the 6 ft MLT dikes at MEC #2 and #3) compared to the occurrence and persistence of given water levels. In developing recommendations for structures at each of the proposed DMMP sites, fetch-exposure, orientation, and success of erosion protection are compared between the proposed sites and the existing sites. Generally, where similarity exists between the proposed and existing site conditions, similar structures are recommended.

TABLE 1. Wind-fetch relationships between sites.

Estimated Fetch Length (Miles)											
	DMMP Wetland Creation Site										
Dir	A	B	D	E	F	I	J	K	128	127A	MEC
N											
NNE										8	
NE		8							14	11	
ENE		11	14	15	3	4			8	7	3
E	1.5	7	8	9	3.5	5 (1)		1.5	5	5	3.5
ESE	4	4	3	3	4	5 (1)		1.5	3	5	4
SE	4	4	2	2	4	1		1.5	3	3	4
SSE	4	3	1	1	4	1.5		1.5	1	3	4
S	5	3	3	2	2	2 (1)	2	1.5	1	4	2
SSW	8	4	6 (2)	5 (1)		16 (7) (1)	16 (4.5)	16 (4.5)	6(2)	4	
SW	14	4					11 (4.5)	11 (4.5)			
WSW	14						7.5	7.5			
W	8						6	6			
WNW	0										
NW											

( ) indicate possible effective fetch due to shoals noted on NOS charts.

The site designations (Site A, B, C, etc.) follow those used in the "Gulf Intracoastal Waterway–Aransas National Wildlife Refuge, Texas; Feasibility Report and Final Environmental Impact Statement."

Sites C, G, & H are not included in the Table. They are located in small water bodies on the North side of the GIWW.

Table 2. Regional wind.

% Wind Occurrences Between 1985-1990								
Wind (Knots)	N	NE	E	SE	S	SW	W	NW
0 - 14	12	7	15	25	9	2	2	3
15 - 29	6	2	3	10	3	0	0.	1
> 30	0	0	0	0	0	0	0	0

Zero (0) indicates value was less than ½ percent.

CONCEPTUAL DESIGNS FOR PROPOSED DMMP WETLAND CREATION SITES

The site designations (Site A, B, C, etc.) used below follow those used in the Section 216 Feasibility Study, titled "Gulf Intracoastal Waterway–Aransas National Wildlife Refuge, Texas; Feasibility Report and Final Environmental Impact Statement, 1995." The locations of the sites are marked in the aerial view of the project in Figure 14.

The designs that are presented should be viewed as conceptual to highlight the design considerations presented in the preceding sections and to highlight approaches to design and construction. As new techniques are developed and perfected the conceptual designs may be modified as needed. In addition, if the dredging and placement cycles presented in the Section 216 Feasibility Study are altered to optimize dredging operations, the characteristics of the conceptual designs should be modified to accommodate. For example, during some of the dredging cycles the dredged material from a given reach is split between two placement areas. It may be deemed more efficient or cost effective to place material in only one site. Hence, the conceptual designs may need to be altered to accommodate the optimized placement schedule.

In all of the conceptual designs where erosion protection structures are required, a water buffer with a fringing stand of smooth cordgrass is designed. This design approach was used based on the recommendations from ICT discussions about marsh design and development. In most cases, the erosion protection structure must be a separate structure from the dredged-material containment dikes because the required elevation of the dikes is much higher than the required elevation for erosion protection. Since two structures are required, it was not unreasonable to recommend that a water buffer be included between them. The shallow water buffer offers better ingress and egress to the site for animals, enhances tidal exchange, and aids in the dissipation of wave energy. It should be kept in mind that the acreage described in the conceptual designs includes only the marsh to be created. Many acres of open water will be sheltered by the DMMP sites, creating additional habitat.

Unexpected but highly desirable ecological features may develop in and around DMMP cells prior to completion of the sites. For example, a cell intentionally filled only partially during the first dredging cycle with the intent of filling it further during the next dredging cycle (maybe 8 years later) may develop valuable open water habitat and a low marsh community. It is possible (and this has happened elsewhere) that some organizations and agencies may not want sites that are developing valuable habitat characteristics to be modified, even if modifications were part of the original plan. Presence of threatened and endangered species may also prevent modification or ongoing use of a placement site. This is not a problem if it does not effect the need for a placement site. Conversely, if an area slated for placement of a few hundred thousand cubic yards of sediment develops valuable habitat, and further placement of dredged material is not desired, alternative arrangements will have to made for placement of the material.

In all of the designs, it was assumed that the average created marsh elevation will be +2.5 ft MLT. This elevation was derived from the natural marsh grids surveyed by WES and District personnel. The topographic elevations in the surveyed areas ranged up to +4.0 ft MLT. Also, surveys of the proposed DMMP sites were reviewed to derive average bed elevations for the sites. The site bed elevations in conjunction with the marsh surface elevation provided an average thickness of dredged material required to fill each site and an improved estimate of total marsh surface area was made for each site. In general, the total acreage estimated during the Section 216 Feasibility Study was an over estimate.

In most of the designs, the placement area for the discharging dredge pipe was nearest the navigation channel to minimize the length of dredge pipe required. As a guide, it is best to keep pump distances below 12,000 - 15,000 ft to avoid the need for booster pumps in the line. When booster pumps are necessary, the cost of dredging is increased. The highest elevations in the sites will be in the areas where the dredge pipe is discharging and should generally slope toward the effluent outlet.

Site A (Welder Flat)

General Location

Site A is located south of the GIWW where it enters San Antonio Bay from the East at Station 728+000. The site is adjacent to Grass Island and the entrance to Shoalwater Bay. The site will provide about 219 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 392 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation in Site A is -3.4 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 5.9 ft thickness of material is needed. Therefore, only 206 acres of the proposed 392 acres can be constructed.

Wave Exposure And Recommended Site Layout

Site A faces long fetches across San Antonio Bay, the longest of which extend from the South and West with reaches as long as 14 miles (Table 1). Fortunately, winds from these quadrants are infrequent and low magnitude (Table 2). The South to Southeast fetches are similar to the same fetches at PA 127A and 128. Therefore, similar structure designs are recommended for Site A as were used at PA 127A. It is recommended that the site be configured to the protected orientation shown in Figure 16. The western side of the site should be oriented in a NW to SE direction in-line with the eastern shoreline of the Victoria Barge Canal north of the site. This configuration would truncate part of the proposed site, but the lost acreage can be added to the eastern side of the site (if permissible) as shown in Figure 16

A breakwater is recommended around the bayward side of the site as shown in Figure 16. The western breakwater would be 1,850 ft long extending southeast from the end of the existing island. The breakwater would then run east for an additional 5,750 ft. No other erosion protection structures will be necessary at this site besides earthen dikes for containing the dredged material in the lee of the breakwater.

The earthen dikes should be constructed at least 100 ft away from the breakwater leaving an expanse of open water between the two structures. The earthen dikes should be roughly parallel to the breakwater. It is recommended that the dikes have an irregular meander to create irregular erosion patterns and enhance development of varying edge habitat. Toward the center of the site, open water with some emergent areas is proposed.

Structures

Offshore Breakwater.

The longest fetches to Site A extend from the South-Southwest to the West with reaches as long as 14 miles (Table 1). Winds from these quadrants are infrequent and low magnitude (Table 2). The fetches from the South to the Southeast are the same as the fetches to PA 127A. A structure similar to that used at PA 127A would therefore suffice at Site A since the exposure to waves is similar. A riprap breakwater is recommended similar to the one used at PA 127A. The breakwater shown in Figure 16 is 7,600 ft long. The crest of the breakwater should be between +3.0 ft and +3.5 ft MLT. The breakwater at PA 127A was 3,700 ft long, had an average crest elevation of +3.2 ft MLT. The water depth around the breakwater at Site A is at least 1.5 ft deeper than at PA 127A. Therefore, more stone will be required per foot at Site A.

Articulated Concrete Mat Around Tip of Existing Island.

The end of the existing island (where Disposal Area 121 is located) should be protected from erosion. The recommended approach to protect the tip of the island is to use articulated concrete mats as a continuation of the mat already being placed along the banks of the GIWW. The mat should be continued sufficiently beyond the point where the breakwater would intersect the island (e.g. 300 ft). The remainder of the shoreline will be protected by the created marsh. A 300-ft wide gap is suggested between the end of the breakwater and the island to enhance tidal exchange behind the site, to help avoid restricting flows into Shoalwater Bay, and to create quiescent areas for development of aquatic habitat.

Earthen Dikes

Earthen dikes 100 ft behind the breakwater should be used to contain the dredged material. The exterior side of the earthen dikes used at Site A should have side slopes of 1:10 for the section below elevation +2.5 ft MLT. This mild slope will dissipate wave energy well and make at least a 10 ft section of slope available for the establishment of *Spartina alterniflora* (between +1.5 ft to +2.5 ft MLT). On the interior side of the dike, the steepest slope possible should be used that does not compromise the stability of the structure. The slopes on the dike between +2.5 and the crest (possibly at +7.0 ft MLT) should be as steep as possible. The Section 216 Feasibility Study assumed a 1:3 side slope was possible with a 10 ft crest width. The crest of the dike will be high, possibly elevation +7.0 ft MLT or greater to accommodate the dredged material, bulking, ponding, and freeboard. Placement and consolidation are being modeled by the District, the results of which will dictate dike elevation. The 1:10 side-slope can be steepened to improve cost if necessary.

This dike design is similar to the dike used for containment at PA 127A which had side slopes between 1:5 and 1:10 based on a 1998 survey. The width of the base of the dike appears to range between 80 and 100 ft. A dike with mild slopes and a wide base is less susceptible to foundation failures. As an added precaution against foundation failures, a 35 ft wide berm should be maintained between the interior toe of the dike and the borrow area for dike material. A similar berm was specified for the dike at PA 127A though the 1998 surveys suggest the berm was sometimes less than 35 ft wide. However, the dike at PA 127A has not been subject to obvious foundation problems.

An example cross section with example dimensions is provided in Figure 17. In the figure, it is assumed that the existing bed elevation is -3.4 ft MLT, the steepest interior side-slope possible is 1:3, the steepest side slopes on the upper portion of the dike are 1:3, and the crest width is 10 ft. The total cross-sectional area is about 550 sq ft. Since the material is borrowed from inside the site, the capacity of the site will be substantially increased by the construction of the dikes. An estimated 21,000 feet of dike may be required to construct the entire site which could require more than 443,000 cubic yards of borrow material. Therefore, the capacity of the site is

substantially increased as the material is borrowed from inside the site. Consequently, the total acreage developed at this site may be reduced by roughly 50 acres.
After construction of the marsh cells is complete, the crests of the dikes should be removed down to an average height of about +2.5 ft MLT. A random variation of ±0.5 ft about that average is encouraged to create more variable habitat conditions. If a dike is to be used for multiple placement operations, then they should not be lowered until all work is done, unless it is required that they be lowered for ecological reasons. The crest material should be pushed to the outside of the dike. However, the dikes may need to be breached to ensure adequate tidal exchange is achieved.

Minimizing the height of dikes is desirable to reduce costs, both in the construction of the dike and in grading the dike after placement. Dike heights can be reduced by increasing the capacity of the cells, using smaller dredges, and placing material in multiple lifts. Oversizing the capacity of the cells provides the dredger flexibility in where the discharging dredge pipe can be located. Oversized cells would be used for placement in subsequent cycles until the cell is filled to the desired elevation. Multiple placements (or lifts) would provide more control over final elevations. The initial costs of oversizing a cell are high since more dike must be constructed. However, subsequent placements should be less expensive because the dikes will not have to be constructed (though some modification or repair may be necessary). Larger cell volumes would allow larger dredges to be used which would save costs.

Construction sequence.
The recommended layout of the site is presented schematically in Figure 16. At the start of each new dredging cycle, when the volume and characteristics of the material are known, and the condition of previous placements is assessed, new placements can be planned. Each new placement would be made to blend with or enhance existing habitat, vegetation, topography and elevation, such as pools, channels, and flats, in an effort to achieve the overall design. Site A is scheduled for dredge cycles roughly every 2.5 years, so opportunities for modification and adaptation will be frequent at this site.

As shown in Figure 16, four placement cells are recommended. The Section 216 Feasibility Study (Table ???) projects that enough dredged material for about 20 ~~22~~ acres of marsh (5.9 ft thickness) will be available every 2.5 years. The recommended sequence of cell construction is presented below. Other sequences are feasible.

The western segment of the riprap breakwater and at least 2,600 ft of the southern segment should be constructed first (approximately 4,500 ft total). In subsequent cycles, the remainder of the southern segment of the breakwater should be constructed. In the lee of the breakwater, Cell 1 as identified in Figure 16 should be constructed using the dike cross-section presented in Figure 17. The cell will be largely protected by the breakwater, though it will be partially exposed to East and East-Southeast fetches. Waves from these directions may erode portions of the exposed dikes, possibly removing the crests of the dikes especially toward the northern end of the cell. This erosion would be a beneficial development since the exposed dike and eastern side of the cell will eventually become the interior of the Site A design. The eroded portions, therefore, will have a more natural appearance. Depending on the rate of erosion of the dikes, subsequent placements in Cell 1 may require some dike repair.

The general elevations for Cell 1 would be highest along the western and northern sides of the site. The elevation might be constant from west to east across the sites in places, but generally, the east and southern portions of the site would be lower than the western and northern portions. Placement would begin at the north end and proceed toward the south end. The effluent discharge structure would be located at the southern end of the site.

Cell 2 and Cell 3 would be constructed sequentially after Cell 1. It may be necessary, prior to the construction of these cells to extend the riprap breakwater to shelter them. Observations of the rates of erosion of Cell 1 should be made to determine the necessity for extending the breakwater. The exposed portion of these cells would erode in a way similar to Cell 1 although the exposure to certain portions of the cells would be greater than Cell 1. As with Cell 1, the exposed dikes will eventually become the interior of Site A. Therefore, erosion of these cells prior to construction of the last cell would be beneficial. The random character of the eroded dike and marsh would create a better environment for the interior of Site A.

The general elevations within Cells 2 and 3 will be highest toward the north (approximately +3.0 ft MLT) and slope downward to low marsh (+2.0 ft to +2.5 ft MLT) on the southern side of the cell. Lastly, the dike for Cell 4 would be constructed. Placement locations within the cells would be determined to coincide with or enhance the existing elevations in the adjacent cells. The intent in Site A is to maintain a low marsh or open water area in the center of the site. Therefore, placement will probably occur along the southern boundary of Cell 4, sloping downward toward the north. The dike at the open-water boundary in Cell 4 could be a very low dike which traps much but not all of the sediment placed in Cell 4 to the south. A moderate amount of sedimentation in the open water area would be beneficial to ensure that the water is not so deep as to trap water in lower layers which may become anoxic.

Site B (False Live Oak Island).

General Location:

Site B is located on the south sides of the GIWW and False Live Oak Island between stations 772+000 and 786+000. Site B will engulf the existing demonstration site at PA 127A. The site will provide about 274 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 407 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -2.4 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.9 ft thickness of material is needed. Therefore, only 257 acres of the proposed 407 acres can be developed.

Wave Exposure And Recommended Layout:

The exposure of the northeast end of Site B is similar to the existing PA 127A. Its exposure to more northerly waves may be increased slightly. Winds and waves from the North occur 18% of the time and 6% of the time the wind speeds are greater than 15 knots (Table 1 & 2). In most other ways the site has the same exposure as PA 127A and PA 128. The recommended layout of the site is shown in Figure 18.

The proposed design of Sites B and D creates a cut just 500 ft wide between the two projects into the GIWW. The cut should be carefully studied to ensure that the restricted cut does not create adverse flow velocities between the two sites due to water level fluctuations in the GIWW as barges pass by. It is not expected that the cut would cause any adverse currents for navigation but that increased velocities may increase deposition in the channel and scour of the bed between the two sites.

Structures:

Riprap Breakwater

Several structures are recommended for Site B. The structure at the northern end of the site should be a riprap structure similar to that used for PA 127A. The crest elevation should be

+3.5 ft MLT. This is the same as the recommended design elevation for the breakwater at PA 127A. The actual average elevation of the PA 127A breakwater is at +3.2 ft MLT, and it has functioned satisfactorily. The structure should be about 3,600 ft long in the orientation shown in Figure 17. The structure will extend in an arc about 2,000 ft out into the bay. A geotextile tube should be continued an additional 2,700 ft parallel to the shoreline. The riprap breakwater should be constructed to protect the northern tip of False Live Oak Island and it should tie into the articulated concrete mat revetment that protects the channel side of the island. The existing riprap breakwater could be removed and its stone used in partial construction of the proposed breakwater.

Geotextile Tube

On the southeast-facing side of the project, geotextile tubes should be sufficient for erosion protection considering the success of the structures at PA 128 that have a similar orientation and wave exposure. The tubes should be built with a crest elevation between +3.0 ft and +3.5 ft MLT which was sufficient for protecting the marsh in PA 127A. The southern tube structure should be about 8,500 ft long. The north end of the southern tube will terminate well behind the tube structure that is an extension of the riprap breakwater. A gap of 300 ft should be maintained between the two structures. Also, as shown in Figure 18, the southeast-facing tube should have openings that allow for periodic access and tidal exchange.

Earthen Containment Dikes

Earthen containment dikes should be constructed about 100 ft behind the geotextile tube and riprap breakwater as shown in Figure 18. The crest elevation of the dikes will be dictated by the needs of the placement operations but may be +7.0 ft MLT or higher. The District is currently modeling post placement consolidation and placement area design requirements. The cross-section of the dike should be similar to the cross-section given for the earthen dike in Site A above. The 1:10 slopes below elevation +2.5 ft MLT should be on the outside of the dike.

The high elevation of the dike crests will be undesirable after placement is completed. It is expected that the exterior dikes will evolve through erosion by waves that periodically propagate over the geotextile tubes. As the dikes erode, a low berm should form on the wave-impacted side of the dike upon which cordgrass should develop. The cordgrass will provide additional wave dissipation. This process can be observed at PA 127A. The interior dikes will have to be lowered by dragline or other more cost-effective method. The use a deadman, pulleys, cables, and crane may increase efficiency since the dikes are reasonably straight. Generally, the crest material should be pushed to the outside of the site.

The estimated average cross-sectional area of the dike will be 443 sq ft. The length of exterior dike at Site B is about 15,700 ft requiring about 241,000 cubic yards of borrow material. Another 8,000 ft of dike is needed along the shoreline of False Live Oak Island. The 5,000 ft of existing placement area dikes on the island may also serve as dikes for the marsh creation site. The remaining 3,000 ft of dike on the island might require an additional 12,000 cubic yards of material. The total volume of borrow material would increase the capacity of the site by 253,000 cubic yards and may subsequently reduce the acreage of the site by roughly 28 acres.

new calcs site B. you did

Construction Sequence:

The existing riprap breakwater at PA 127A is still in excellent condition and should be used for as long as possible. The first cells for Site B should be constructed south of the existing PA 127A behind the southern geotextile tube structure discussed above. Earthen dikes should be used to contain the dredged material behind the geotextile tubes. The same design guidance given for the dikes at Site A should be used here. As suggested for Site A, the cells in Site B should be oversized to provide placement flexibility for the dredging contractor, allow lower dike crest elevations, or permit the use of a larger dredge. The area in the lee of the southern geotextile tube structure is about ~~180~~ 263 acres. It may require ~~two~~ or ~~three~~ four or five dredging cycles to fill this area which may take up to ~~16~~ 24 years according to the dredging schedule provided in the Section 216 Feasibility Study. Since placement in this area is not scheduled to begin until the year ~~8~~ 9 of the DMMP, work on the other areas of Site B will not begin until the last half of the DMMP.

this change signific

Once the southern end of Site B is constructed and filled, the north end of Site B will be developed.

The marsh configuration is shown schematically for the southern cell in Figure 18. The site is largely high marsh, though expanses of low marsh and open water exist. In Figure 18, the high marsh is toward the island side of the site, sloping to low marsh and open water toward the bay. Providing that adequate tidal exchange is present in the open-water areas, valuable aquatic habitat for fish, shellfish, and aquatic plants should exist.

Site C (Mustang Lake)

General Location:

Site C is located in Mustang Lake (sometimes referred to as McMullen Lake) near Station 776+000 on the north side of the GIWW at the eastern end of the ANWR. The site will provide about maybe 37 31 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 43 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -1.8 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.3 ft thickness of material is needed. Therefore, only 31 acres of the proposed 43 acres can be developed.

Wave Exposure and Recommended Layout

The recommended layout and design of Site C is provided in Figure 19. The site is exposed to the northern fetches across Mustang Lake with maximum lengths of about one mile and to the effects of water-level fluctuations in the GIWW. The layout of the marsh and structures proposed in the Section 216 Feasibility Study was intended to restrict the opening of the lake to the GIWW to about 150 ft. Since the estimated final acreage at this site is less than expected in the proposed design, the recommended layout of the site would remove that portion of the proposed site that restricts the opening to the Lake. The constriction would likely create erosive conditions through the cut and construction and protection of structures from erosion in this location would be difficult.

Structures:

At Site C, the containment and erosion protection dike is divided into three sections with different characteristics: the segment that is exposed to the north, the segment near the opening of the lake to the GIWW, and the segment adjacent to the existing shoreline. Each section of the dike is considered separately below.

North-facing dike.

The dike around the north side of the site should not require erosion protection. The longest fetch is due north and is about one mile long. Generally, exposure to a one mile fetch is tolerable for successful development of an unprotected marsh (Knutson et al 1981, and communication with the Plant Material Center in Coffeeville, MS). The development of a cordgrass fringe that would stabilize and protect the dike from rapid erosion is expected.

The recommended cross-sectional design of the dike is the same as the dike recommended for Site A with exterior side-slopes of 1:10 below elevation +2.5 ft MLT and all other side-slopes as steep as possible. The crest of the dike will be high, possibly elevation +7.0 ft MLT or greater to accommodate the dredged material, bulking, ponding, and freeboard. Placement and consolidation are being modeled by the District, the results of which will dictate recommended dike elevation. The dike should be constructed from bed material inside the placement area. The length of the dike will be about 2,200 ft and will require up to 29,000 cubic yards of borrow material. This may reduce the size of the site by 4.5 acres. The dike should be constructed from material borrowed from inside the placement area. The composition of the material is unknown at present, so its adequacy should be investigated for achieving the dike design described below.

After dredged-material placement operations are completed, the top of the dike should be removed down to an average height of +2.5 ft MLT. Variation about this elevation (±0.5 ft) is recommended to create a more variable marsh edge. The material should be pushed to the outside of the dike.

Optional Offshore Segmented Breakwater

If the USFWS, ICT or the District are not satisfied with the approach of using an unprotected earthen dike on the northern side of the site, then a segmented structure such as sand-filled geotextile tubes should be placed offshore from the project to dissipate waves from the north as shown in Figure 19. The length of the structure would be about 2,000 ft to 2,500 ft. An acceptable crest elevation for the tube would be +2.0 ft MLT. This elevation was adequate for the marsh at PA 128 which was exposed to 14 mile fetches and the predominate southeast winds. The gap width between segments could be larger than described for Site D, (e.g 25 ft -50 ft as opposed to 10 ft), because of the lower wave-energy.

Dike Adjacent to Existing Shoreline.

Along the lake shoreline, damage to the existing marsh should be avoided. The containment dike for dredged material should be constructed against but not on the existing marsh. The proposed narrow water buffer between the dike and the existing spit is not recommended. It would be better to merge the placement area elevation contours into those of the existing marsh. The interior side slopes of the earthen dike should be as steep as possible to minimize borrow volume and construction costs. The material should be dug from inside the placement area. The elevation of the crest of the dike will be the same as the northern dike which depends on the needs of the placement operations as discussed above. The dike is 2,200 ft long and could require as much as 22,000 cubic yards of borrow material. This may reduce the size of the site by 3.5 acres.

Dike Near Entrance to Lake.

The segment of the dike used near the entrance of the lake to the GIWW should also be constructed of material borrowed from the placement area. The dike should be protected with an articulated concrete mat similar to the mats placed along the bank of the GIWW and should tie in neatly with those mats.

The articulated mat should be used from the existing channel mat to well passed the constriction. Simulations of the flows through the entrance due to barge traffic would help determine how far into the lake the matting is needed. The dike should grade into the cross section of the north-facing dike which was described above. An articulated mat should also be placed along the shoreline on the opposite side of the constriction.

Geotechnical investigations will be needed to determine if the dike-building material at the site is of sufficient quality to support the weight of a concrete mat.

Site D (PA 128)

General Location

Site D is located south of the GIWW and on the south side of PA 128 near station 788+000. The site will provides ~~57~~ 66 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 90 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -2.4 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.9 ft thickness of material is needed. Therefore, only 57 acres of the proposed 90 acres can be developed.

Dredging quantities from schedules have changed. Place 518,000 cy. instead of 449,280 cy.

Wave Exposure and Recommended Layout.

The wave exposure of Site D is similar to that for PA 128 as shown in Table 1. The longest fetches (up to 14 miles) are toward the east and northeast. The site appears to be sheltered from waves out of the south and southwest by shoals.

The proposed layout and design of Site D is shown in Figure 20. Around the north and southeast-facing sides of the project are geotextile-tube structures. Along the longer, southeast-facing side of the site, it is recommended that the tubes be segmented with gaps of approximately 10 ft. The gaps are recommended to improve access to the site, provide tidal exchange, and create variation in the marsh behind the tubes. About 100 ft from the tube, an earthen dike will be constructed to contain the dredged material. Inside the site, the marsh (or dredged material surface elevation) will be highest along the boundary of Site D with PA 128 and lowest toward the bayside of the site. The low areas are most exposed to waves, but the low marsh vegetation that will develop there and the shallow open water that will exist there are best suited to dissipate waves.

Structures

Northern Geotextile Tube.

The geotextile-tube structure along the northeast side of Site D should be built to crest elevation between +3.0 ft and +3.5 ft MLT. The structure should tie into the northern structure of PA 128.

The two structures should be in-line with one another. (The proposed design in the Section 216 Feasibility Study showed the structure for Site D bowing outward from the structure at PA 128. That would create a potential problem at the union of the structures where waves would converge.) The northeast geotextile-tube structure will be approximately 1,150 ft long.

Southeast Geotextile Tube

The geotextile-tube structure along the southeast side of the site should have the same crest elevations as the tube on the north side of the site and it should be segmented. At the north end, the first segment should connect with the bayward end of the northeastern tube discussed above. At the south end of the site, the segmented geotextile-tube structure should wrap around the site toward the northwest and terminate. This sufficiently protects the site from wind-waves in the bay.

? we have scour right Now at PA128 w/ a deflated tube the creating 10 ft op

The gaps between tube-segments should be small, only about 10 ft wide. The gaps will allow access to the site from the bayside, enhance tidal exchange, and create some variation in topography and habitat behind the structures. The structure should effect the leeward dike similar to the way segmented breakwaters in other settings create small crescent-shaped shorelines behind the gaps. The gaps are recommended every 200-250 ft. The actual effectiveness of the gaps will be monitored. After monitoring, it may be that larger gaps and more or less frequent gaps are needed.

The total length of geotextile tube on the southeast and southwest sides of the site is approximately 3,750 ft.

Interior Dikes

Earthen containment dikes should be constructed about 100 ft behind the geotextile tube structure as shown in Figure 20. The crest elevation of the dikes will be dictated by the needs of the placement operations but may be +7.0 ft MLT or higher. The District is currently modeling post placement consolidation and placement area design requirements. The cross-section of the dike should be similar to the cross-section given for the earthen dike in Site A above. The 1:10 slopes below elevation +2.5 ft MLT should be on the outside of the dike.

The cross-sectional area of the dike is 443 sq ft. The length of earthen dike is approximately 7,000 ft. Therefore, the volume of borrow material required for the dike is estimated at 107,000 cubic yards. This would increase the capacity of the site and consequently reduce the final acreage by 15 acres.

The high elevation of the dike crests will be undesirable after placement is completed. It is expected that the exterior dikes will evolve through erosion by waves that periodically propagate over the geotextile tubes or through the gaps between the tubes. As the dikes erode, a low berm should form on the wave-impacted side of the dike upon which cordgrass should develop. The cordgrass will serve as additional wave dissipation. The interior dikes will have to be lowered by dragline or other more cost-effective method. The use a deadman, pulleys, cables, and crane may increase efficiency since the dikes are reasonably straight. Generally, the crest material should be pushed to the outside of the site.

A portion of the earthen dike is exposed to boat wake generated by traffic on the GIWW and may need protection. Options for protecting this dike if necessary are a low-crested geotextile tube (+1.5 - 2.0 ft MLT), articulated concrete mats similar to those used along the waterway, or a mound crushed limestone. If the limestone reef is built in the configuration of natural oyster reefs, it may provide oyster habitat as well as wave erosion protection.

Effluent Outlets

Effluent outlets should be located at the bayward corners of the project as noted in Figure 20. The placement operation will require a weir structure to decant water from the site. M the use of either outlet will depend on where the dredged material discharge pipe is located and the configuration of the material settling in the site.

Additional Considerations

After dredged material placement is complete, the effluent structure may have to be dismantled and removed. The dikes must be lowered so as not be an obstruction for whooping cranes; and depending on the final elevations of the dredged material, the crests of the dike may need to be selectively breached to allow for occasional tidal inundation. Material from the dikes should be pushed toward the outside of the dikes. The tube on the south end of PA 128 should be removed if it is clear that the configuration of Site D shelters that end of the project from waves. Even in its present setting, the south end of PA 128 is exposed to very little wave energy. If possible, as much of the geotextile fabric as possible should be removed from the crest of the existing tube on the southeast side of PA 128.

Site E (Rattlesnake Island)

General Location

Site E is located on the south side of the GIWW and on the south side of Rattlesnake Island between Stations 792+000 and 798+000. The site will provide 117 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 147 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -1.4 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 3.9 ft thickness of material is needed. Therefore, only 117 acres of the proposed 147 acres can be developed.

Wave exposure and Recommended Layout

Site E has a similar exposure to waves as Site D to the east and northeast. From east to south, though, the fetches are much shorter due to the extended width of Matagorda Island at that point and to shoals and reefs that can be seen in aerial photographs and which are marked on the NOS Nautical Chart #11315. The longer fetches to the east and northeast may be shortened by shoals and reefs, however, their effectiveness at dissipating waves from these directions is unknown. It has been observed that the northern end of Rattlesnake Island is actively eroding due to its exposure to the northeast. Therefore, structures are recommended here that are similar to the structures used at PA 128 and designed for Site D.

The recommended layout for Site E is shown in Figure 21. The site should be protected on the northeast end with a continuous geotextile-tube structure. On the southeast side of the site, a segmented geotextile-tube structure is recommended similar to that recommended for Site D. The gaps between the segmented structure should be between 10 ft - 25 ft. Near the shoreline of Rattlesnake Island, the containment dike for the dredged material should meander creating areas that are more open and constricted than the 300 ft buffer proposed in the Section 216 Feasibility Study. The varying width would provide more opportunity for habitat development.

Structures

Northeast-Side Geotextile Tube

The geotextile tube on the northeast side of the site should be similar to the tube on the northeast side of Site D. It should be built to an average crest elevation of +3.0 ft with allowance for ±0.5 ft of variance. The structure should start 300 ft from the Rattlesnake Island shoreline and terminate at the junction with the southeast-facing structure about 1,500 ft offshore.

Southeast-Side Geotextile Tube

The geotextile tubes along the southeast side of Site E should have the same crest elevations as the tube on the northeast side of the site. The gaps between the tube-segments should be between 10 ft - 25 ft. The gaps allow access to the site from the bayside, enhance tidal exchange, and create some variation in topography and habitat behind the structures. It is expected that the structure will behave similar to segmented breakwaters in other settings where small crescent-shaped shorelines form behind the gaps. The gaps are recommended every 200-250 ft. The total length of the segmented breakwater should be approximately 5,500 ft. The breakwater will extend 500 ft beyond the southwest end of the placement cell.

Shoreline Protection

An articulated concrete mat should be used on the shoreline of Rattlesnake Island to dissipate waves that are reflected or diffracted into the shoreline by the breakwater on the northeast side of the site. The protection should extend from the GIWW around the end of PA 129 and 300 ft past the point where the geotextile tube breakwater would intersect the shoreline.

Interior Containment Dikes

Earthen containment dikes should be constructed approximately 100 ft behind the geotextile tube structure and around the placement areas as shown in Figure 21. The crest elevation of the dikes will be dictated by the needs of the placement operations, but may be +7.0 ft MLT or higher. The cross-section of the dike should be similar to the cross-section given for the earthen dike in Site A. The 1:10 slopes should be on the outside of the dike. The average cross-sectional area of the dike is about 350 sq ft. The total length of the dike required is approximately 12,000 ft, so the dike will require approximately 145,000 cubic yards of borrow material. Therefore, the capacity of the site may be increased or the final area reduced by up to 25 acres.

The high elevation of the dike crests will be undesirable after placement is completed. It is expected that the dikes near the breakwaters will evolve through erosion by waves that periodically propagate over the geotextile tubes or through the gaps between the tubes. As the dikes erode, a low berm should develop on the wave-impacted side of the dike upon which cordgrass should develop. The cordgrass will serve as additional wave dissipation. This process can be observed at PA 127A. The dikes adjacent to the Rattlesnake Island shoreline will have to be lowered manually.

Construction Sequence

The scheduled dredging maintenance plan for the waterway proposed in the Section 216 Feasibility Study indicates that placement in Site E will be done every 8 years and approximately 41 acres of marsh will be created each time. The proposed construction sequence begins with the first cell at the south end of the site and works toward the north. It is recommended that the north end of the site be developed first. As suggested for Site A, the cells in Site E should be oversized to provide placement flexibility for the dredging contractor, allow lower dike crest elevations, or permit the use of a larger dredge.

The first cell, Cell 1, should be oversized to contain about 60 acres as shown in Figure 21 and used for the first two placements. The northeast-side breakwater and about 3,500 ft of the southeast-side segmented breakwater should be constructed. The first placement in Cell 1 should be toward the north end of the cell and slightly toward the Rattlesnake Island side of the center of the cell. The highest elevations will be in this discharge area and slope toward the northeast- and southeast-facing breakwaters. Effluent weir structures should be located at the south end of the site as suggested in the figure. The effluent outlets in the cell will depend on where the discharge pipe is located and the condition of the site at the time of the placement. Discharge structures could also be installed in the breaches made in the dike after previous placement operation, if deemed necessary.

Cell 2 and the remainder of the segmented breakwater should be built for the final placement operation.

After each placement, the dikes around each site must be breached to ensure adequate tidal exchange. The breaches must be closed prior to the next placement. Also, after all placements are completed in a cell the elevation of the dike crest must be reduced and blended into the surrounding elevations.

Site F (North Bludworth Island)

General Location

Site F is located south of the GIWW on the south side and toward the north end of Bludworth Island between Stations 808+000 and 814+000. Site F overlaps part of the Mitchell Energy Company wetland creation site constructed in 1995. The site will provide about 73 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 96 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -1.6 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.1 ft thickness of material is needed. Therefore, only 73 acres of the proposed 96 acres can be developed.

Wave exposure and Recommended Layout

Site F has an exposure to waves similar to the MEC sites and PA 127A from the east to the south. The longest fetches are to the southeast which is the dominant wind direction. Winds blow from the southeast 35% of the time and 10% of the time the winds speed is above 15 knots. The fetch length is about 4 miles. The Mitchell Energy sites have earthen dikes overlaid with articulated concrete mats. A separate sand-filled geotextile tube is recommended here for erosion protection.

The recommended layout for Site F is shown in Figure 22. The site should be protected on the southeast side by a straight geotextile tube structure. The exposure of Site F on either end is minimal because Ayers Island on the north end and shoals on the south end reduce the fetches to less than a mile. If the segmented geotextile-tube structures at the DMMP sites constructed prior to Site F are successful, then a segmented geotextile tube at this site should be considered.

The alignment of the dikes constructed around the site should have a slight meander. The placement area should terminate about 500 ft from either end of the tube structure. The dikes should angle back away from the tube as shown in the drawing to minimize the exposure of the dikes to waves.

Structures

Geotextile-Tube Breakwater

The geotextile-tube structure along the southeast side of the site should have a crest elevation that is between +3.0 ft and +3.5 ft MLT. This is consistent with the elevation of the structure used at PA 127A which has a wave exposure similar to this site. If the use of gaps in the structures at previously constructed sites (such as Sites D & E) is successful, then it is recommended that they be used here as well. The tube is roughly parallel to the Bludworth Island shoreline from 1,200 ft - 2,000 ft offshore. The total length of the structure is approximately 6,500 ft. The structure should extend about 500 ft beyond the ends of the marsh to help protect the containment dikes from erosion.

Interior Containment Dikes

Earthen containment dikes should be constructed approximately 100 ft behind the geotextile tube structure and around the placement area as shown in Figure 22. The crest elevation of the dikes will be dictated by the needs of the placement operations but may be as high as +7.0 ft MLT. The cross-section of the dike should be similar to the cross-section given for the earthen dike in Site A. The 1:10 slopes should be on the outside of the dike. The cross-sectional area of the dike is 370 sq ft. The total length of the exterior dike is approximately 12,000 ft. Therefore, the volume of borrow material required would be almost 153,000 cubic yards which increases the capacity of the site and may decrease the final acreage by as much as 25 acres.

High elevations on the dike crests will be undesirable after placement is completed. It is expected that the dikes near the breakwaters will evolve through erosion by waves that periodically propagate over the geotextile tubes. As the dikes erode, a low berm should develop on the wave-impacted side of the dike upon which cordgrass should develop. The cordgrass will serve as additional wave dissipation. The dikes on the landward side of the site will have to be lowered manually.

Construction Sequence

The placement area can be constructed in any sequence. It is recommended that the placement cells be oversized to provide flexibility in dredged material placement, allow lower dike crest elevations, or allow a larger dredge to be used. Whichever and however the cells are constructed the geotextile-tube breakwater should extend 500 ft beyond either end of the cells. That is, if only one cell is constructed, then the breakwater should extend 500 feet to either side of that cell. Dredged material placement at this site is scheduled for every eight years and it is expected that on average enough material will be available to build 18 acres of marsh.

Site G (Southwest Peninsula at entrance to Sundown Bay)

General Location

Site G is located in Sundown Bay at Station 808+000 on the north side of the GIWW. The site will provide about 30 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 24 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is assumed to be 0.0 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 2.5 ft thickness of material is needed. Therefore, 30 acres of marsh development is possible. To accommodate the additional acreage the, the site should be extend 200 ft wider. Alternatively, the length of the site could be increased by 1,500 ft. (The ICT may determine that the increased width of the site encroaches on critical whooping crane habitat and so recommend against that alternative.)

Wave Exposure and Recommended Layout

The layout of the marsh and structures are intended to replace some of the existing island that has been lost to erosion (Figure 23). The layout of the site, erosion protection and containment structures, and marsh design are outlined below.

At Site G, the containment and erosion protection dike is broken into three sections: the section that parallels the GIWW and wraps around into the bay, the section that is exposed to short fetches to the Northwest, and the section that parallels the existing shoreline of the bay. Each section is considered separately below.

Northwest-facing dike.

The dikes along the northwest side of the site should not require protection. The longest fetches are less than one mile and oriented toward the North and West. Winds from those quadrants are less frequent than from the South and East. Generally, one mile is considered tolerable for successful development of an unprotected marsh. The development of a cordgrass fringe on this dike is expected and should help stabilize and protect the dike from erosion. The dike should be constructed from material dug from inside the placement area. The composition of the material is unknown at present. Therefore, its adequacy should be investigated for achieving the dike design described below.

The unprotected dike on the Northwest side of the site should be the same as the containment dike described for Site A. It should have an exterior side-slope of 1:10. This mild slope would dissipate wave energy well and make at least a 10-ft section of slope available for the establishment of smooth cordgrass (between +1.5 ft to +2.5 ft MLT). The northwest-facing dike would have a cross-sectional area of 240 sq ft, is about 3,400 ft long, and may require about 28,000 cubic yards of borrow material. This will increase the capacity of the site and so may reduce the final acreage by about 7 acres.

After placement the top of the dikes should be removed to an average elevation of +2.5 ft MLT. Variation of ±0.5 ft about this elevation is recommended to create a desirable marsh edge. The material should be pushed to the outside of the dike.

Dike Adjacent to Existing Shoreline

Along the island shoreline, damage to the existing marsh should be avoided. Therefore, the containment dike for dredged material should be constructed against but not on the existing marsh. The narrow water buffer between the dike and the island as proposed in the Section 216 Feasibility Study is not recommended. It would be better to grade the placement area elevation contours into those of the existing marsh. The side-slopes of the earthen dike should be made as steep as possible to minimize volume and construction costs. The reduced cross-sectional area of the dike is estimated at 210 sq ft. The dike adjacent to the shoreline will be approximately 2,000 ft long and therefore will require 14,400 cubic yards of material. The material should be dug from inside the placement area. The elevation of the crest of the dike will depend on placement operations, but an elevation of +7.0 ft MLT is estimated.

Dike parallel to the GIWW.

The section of the dike parallel and adjacent to the GIWW should also be constructed of material dug from the placement area. The dike should be protected with an articulated concrete mat similar to the mats placed along the bank of the GIWW and should tie into those mats. Earthen dikes are recommended in place of geotextile tubes because tubes can not be used to make the proposed curved structure and small openings in the abutment between tubes or between the tube and the existing shoreline may allow the flow of water or sediments. Normally, achieving a tight abutment between tubes is not a concern. However, adjacent to the waterway where water levels drop rapidly with the passage of barges hydraulic gradients are created that will force water through any openings between the channel and adjacent water bodies. The rapid flow of water would take with it dredged material. An earthen dike can be constructed that completely isolates the placement area from the channel.

The containment dike should wrap around the placement area into Sundown Bay on a gentle curve to prevent undesirable flows such as steep gradients or vortices from occurring. The dike, covered by the articulated concrete mat, should wrap around to the backside of the site, for full protection. The mat-covered dike should grade into the cross section of the northwest-facing dike described above.

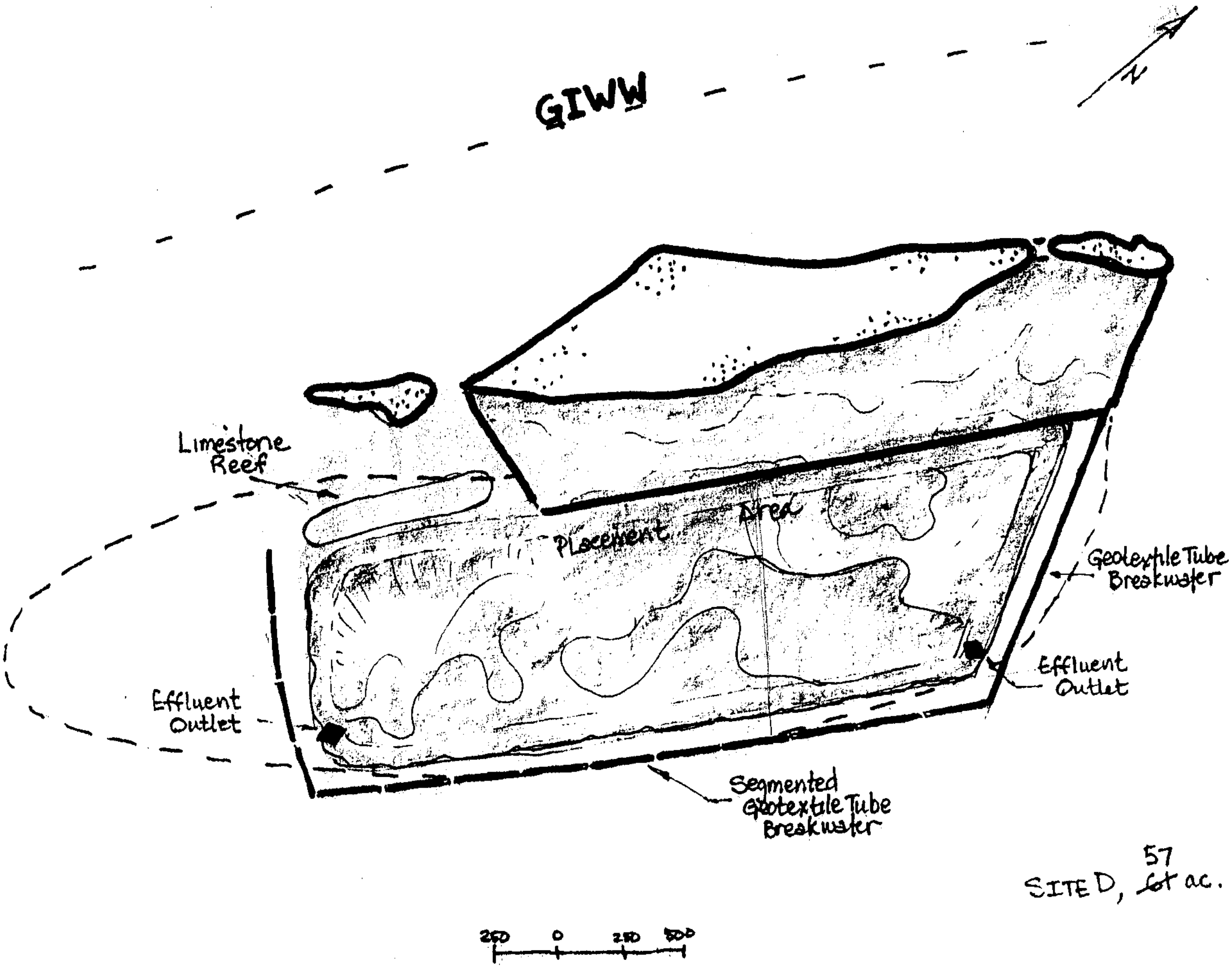
Geotechnical investigations will be needed to determine if the dike-building material at the site is of good quality and can satisfactorily support the weight of the concrete mat.

Construction Sequence

Site G is scheduled for placement during the first dredging cycle of the DMMP. Only one placement is scheduled for this site. Because this site is so narrow and is an extension of the existing island, the created marsh should be made to blend with the characteristics of the exiting island habitat. Post placement contouring from the periphery may be feasible at this site since it is so narrow.

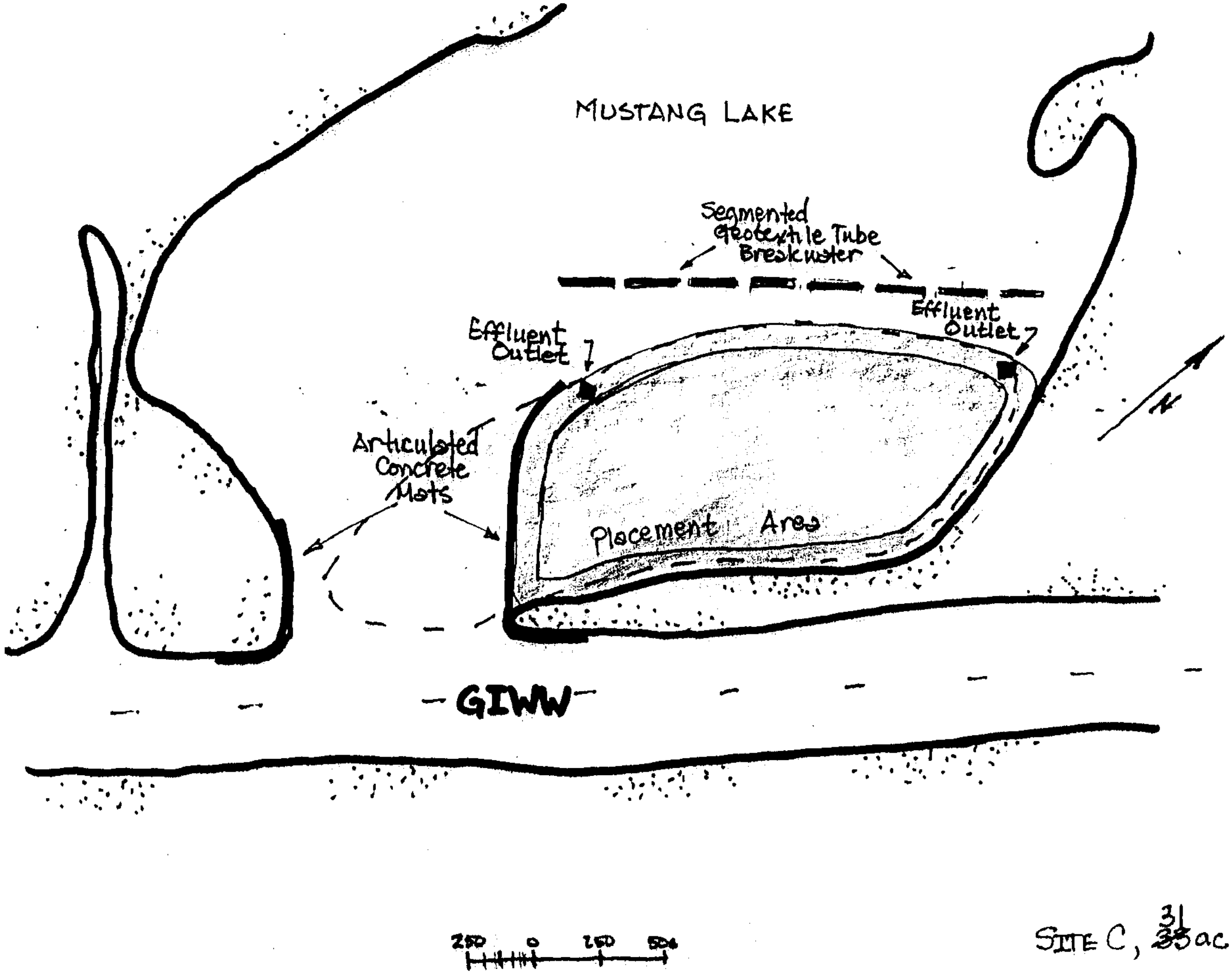
Additional Considerations

Site G is located at the point where the GIWW becomes constricted by banks on both sides of the channel. As barge traffic passes by this location, strong currents will be generated around the end of Site G, just as they do now around the end of the existing island. It is recommended that a simulation of the currents generated by barges at this location be made to help determine how far the concrete mat should be extended around the point of Site G. The ERDC HIVEL model could be used for such simulations.



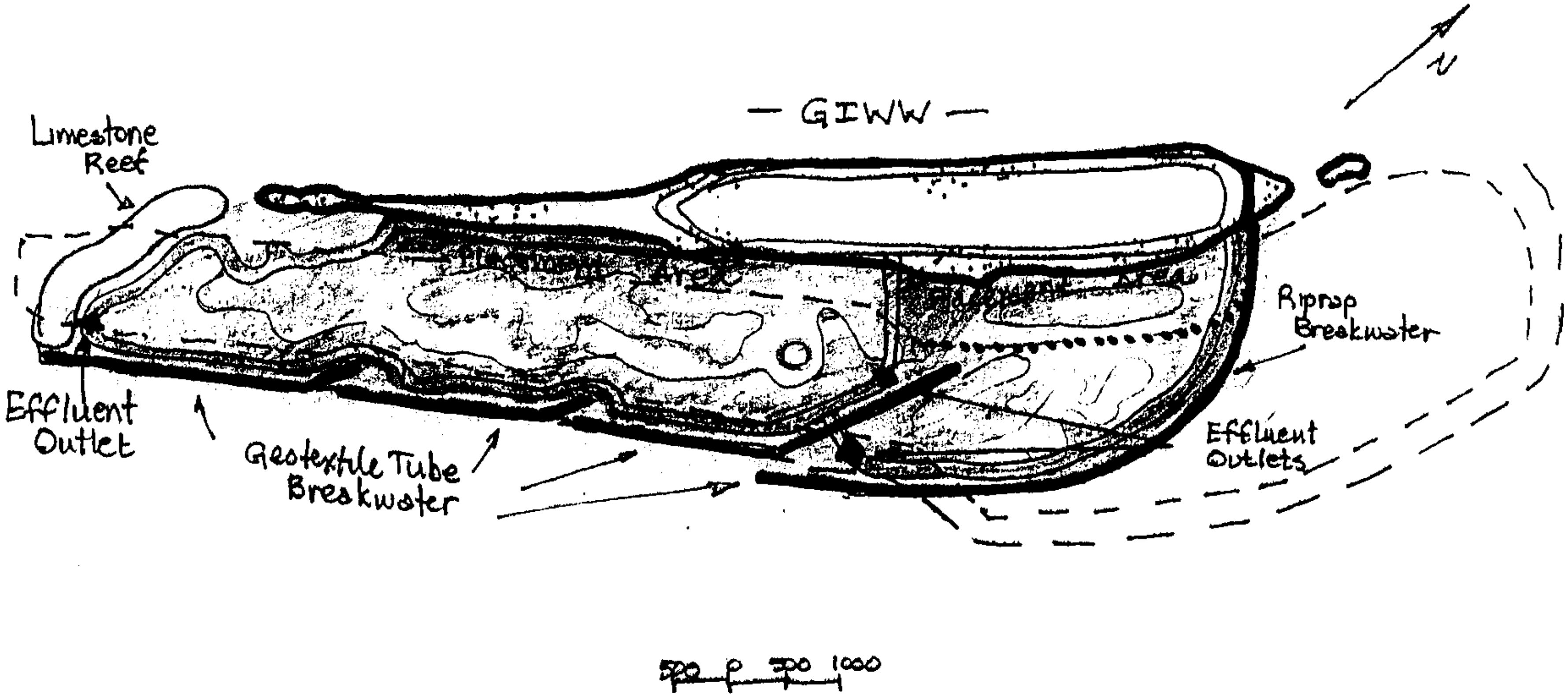
SITE D, ~~61~~ 57 ac.

Fig 20



SITE C, ~~35~~ 31 ac.

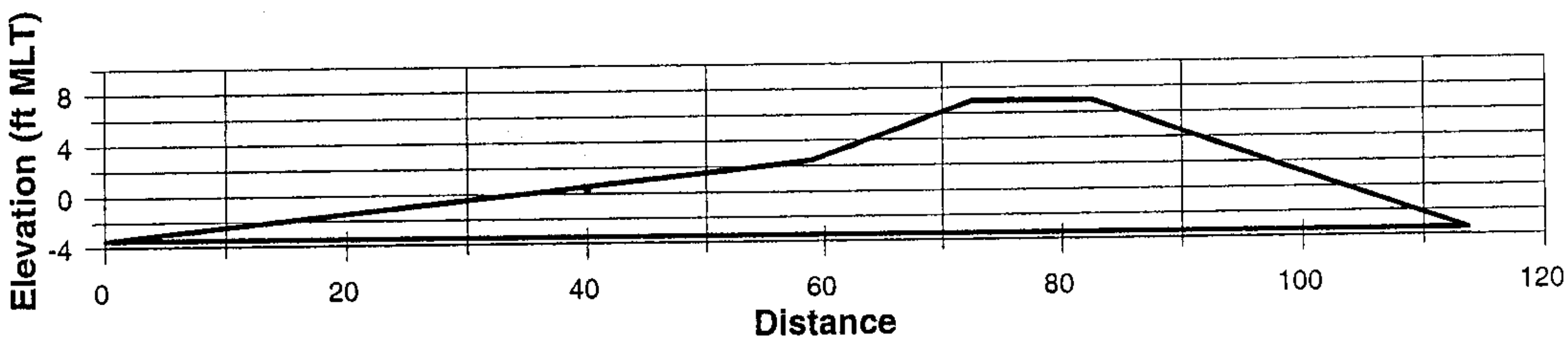
Fig 19



SITE B, ~~274~~ 257 ac.

Fig 13

Example Cross-Section
of Dike (550 sq ft)



Site H (South Entrance to Sundown Bay)

General Location

Site H is located on the north side of the GIWW at Station 816+000. The site as proposed will partially close off an opening from the GIWW in the southern portion of Sundown Bay. The site will provide about 16 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 10 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is +0.6 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 1.9 ft thickness of material is needed. Therefore, 16 acres of new marsh can be developed.

Wave Exposure and Recommended Layout

It is recommended that the opening between the GIWW and Sundown Bay be completely closed off by Site H as shown in Figure 23. Historically, the opening was not present. On the NOS Nautical Chart #11315 (1980), the entrance is closed. Another entrance further to the Southwest was the original (and only other) entrance to that end of the bay. If the entrance at Site H is closed off, flows through the other entrance may increase to accommodate flows. If complete closure is undesirable, then careful study of the proposed 50-100 ft opening should be made to ensure that high current velocities through the opening are not a problem. Barge traffic on the GIWW will generate the worst flow conditions. If the banks of the opening are protected from erosion by concrete mats, the bed of the opening may still be vulnerable to erosion and deepening.

The containment and erosion protection dike is separated into three segments: the segment that closes the opening to Sundown Bay from the GIWW, the segment that is exposed to the Northwest, and the segment that parallels the existing shorelines. Each section is considered separately below.

Structures

Northwest-facing dike.

The dikes along the northwest side of the site should not require protection. The longest fetches are oblique, less than one mile, and oriented toward the North. Winds from the north are less frequent than from the South and East. Generally, one mile is considered tolerable for successful development of an unprotected marsh. The development of a cordgrass fringe on this dike is expected and should help stabilize and protect the dike from erosion. The dike should be constructed from material dug from inside the placement area.

The dike should be the same as the containment dike described for Site A. It should have an exterior side-slope of 1:10 up to elevation +2.5 ft MLT. This mild slope will dissipate wave energy well and make at least a 10 ft section of slope available for the establishment of smooth cordgrass (between +1.5 ft to +2.5 ft MLT).

The cross-sectional area of the dike in the figure is 200 ft^2. The length of the dike is approximately 2,000 ft so approximately 13,800 cubic yards of borrow material will be required. This will increase the capacity of the site and may reduce potential area by nearly 5 acres.

After placement, the crest of the dike should be removed down to an average elevation of +2.5 ft MLT. Variation of ±0.5 ft about this elevation is recommended to create a desirable marsh edge. The material should be pushed to the outside of the dike.

Dike Adjacent to Existing Shoreline

Along the adjacent shorelines, damage to the existing marsh should be avoided. The containment dike for dredged material should be constructed against but not on the existing marsh. The narrow water buffer between the dike and the shoreline as proposed in the Section 216 Feasibility Study is not recommended. The side-slopes of the earthen dike should be made as steep as possible to minimize volume and construction costs. The reduced cross-sectional area is estimated to be about 180 ft^2. The length of the dike is approximately 1,500 ft. The volume needed to construct the dike is approximately 9,300 cubic yards. This will increase the capacity of the site and reduce the possible marsh area by about 3 acres. The elevation of the crest of the dike will depend on placement operations, but an elevation of +7.0 ft MLT is estimated. The dike should be lowered after placement. The created marsh elevation should blend into the elevation of the existing marsh.

Dike parallel to the GIWW.

The section of the dike parallel and adjacent to the GIWW should also be constructed of material dug from the placement area. The dike should be protected with an articulated concrete mat similar to the mats placed along the bank of the GIWW and should tie into those mats. Earthen dikes are recommended rather than geotextile tubes because small openings in the abutment between tubes or between the tube and the existing shoreline may allow the flow of water or sediments out of the placement area. Normally, achieving a tight abutment between tubes is not a concern. However, adjacent to the waterway where water levels drop rapidly with the passage of barges hydraulic gradients are created that will force water through any openings between the channel and adjacent water bodies. The rapid flow of water would tend to take with it dredged material. An earthen dike can be constructed that isolates the placement area from the channel.

Geotechnical investigations will be needed to determine if the dike-building material at the site is good quality and can satisfactorily support the weight of the concrete mat.

Construction Sequence

Site H is scheduled for placement during the first dredging cycle of the DMMP. Only one placement is scheduled for this site. Because this site is so small, the created marsh should be made to blend with the characteristics of the exiting island habitat.

Additional Considerations

If the opening from the GIWW into Sundown Bay is not completely closed off by site H, then it is recommended that a simulation of the flows through the restricted opening be made to determine if the resulting velocity magnitudes are detrimental to structural stability. The ERDC HIVEL model can be used to conduct such simulations.

10i. Site I (South Bludworth Island)

General Location

Site I is located on the south side and toward the south end of Bludworth Island between stations 822+000 and 830+000. The site will provide about 172 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 222 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -1.5 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.0 ft thickness of material is needed. Therefore, only 172 acres of the proposed 222 acres can be developed.

Wave Exposure and Recommended Layout

Site I, as shown in Figure 24, is one the most sheltered sites in the DMMP as long as it is kept within the protected cove of Bludworth Island as proposed in the Section 216 Feasibility study. If the site extends too far offshore to the southeast it may then be exposed to waves generated across the longer fetches of Aransas Bay. The general exterior configuration of Site I should remain as proposed. On the interior of the site, the shape of each cell is modified to create variation across the site.

A segmented breakwater is recommended along the offshore side of the site. Behind the breakwater and surrounding each cell are earthen dikes. The cells are generally the same size as proposed in the Section 216 Feasibility Study, except that the first two cells are merged into one large cell.

Structures

Offshore Breakwater

The offshore breakwater will consist of a segmented geotextile-tube structure. The average tube crest elevation should be +3.0 ft MLT. The geotextile tube segments should be 200 ft - 250 ft long and the gaps between segments should be less than 25 ft. The gaps provide access to the site, enhance tidal exchange, and create variation in the erosion of the leeward dike. the structure will be segmented and aligned roughly parallel to the shoreline in the southwesterly direction.

The length of this portion of the structure is 6,000 ft.

On the north end of the site, a non-segmented reach of structure should begin about 300 ft from the shoreline and extend southward terminating about 1,800 ft offshore. The length of this portion of the structure the structure is 1,500 ft.

Earthen Containment Dike

An earthen dike should be constructed behind the geotextile tube structure. The dike should be set back from the structure about 100 ft to enhance tidal exchange and access to the site by animals. The dike design discussed for Site A should be used here, where the exterior slope up to elevation +2.5 ft MLT is 1:10 and all other slopes are made as steep as possible. The proposed dike will have a cross-sectional area of 360 sq ft. The total length of dike required is about 19,000 ft. Therefore, approximately 236,000 cubic yards of borrow material are required. This will increase the capacity of the site and may reduce the final acreage by approximately 39 acres.

Construction Sequence

The northern most cell should be constructed first. The northern most 4,500 ft of geotextile tube breakwater should be constructed. The structure should extend 1,300 ft beyond the limits of the northern cell and offer protection to the leeward earthen dikes from waves out of the southeast and east. The dikes will have limited exposure to waves from the south. Limited erosion of the dikes is considered beneficial as they will eventually become part of the interior of the site.

During the next dredging cycle, the breakwater should be extended across the entire length of the project and the southern most cell should be constructed. The center of the site should be constructed last.

10j. Site J (Dunham Bay, West of GIWW)

General Location

Site J is located at the western end of the Aransas National Wildlife Refuge on the north side of the GIWW between stations 832+000 and 840+000. The site will provide about 115 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 148 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -1.5 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.0 ft thickness of material is needed. Therefore, only 115 acres of the proposed 148 acres can be developed.

Wave Exposure and Recommended Layout

The general layout of Site J given in the Section 216 Feasibility Study is recommended (Figure 25). The site is exposed to long fetches ranging up to 16 miles from the southwest (Table 1). Winds are mild and infrequent from this direction. Table 2 indicates that winds from the southwest and west account for about 4 % of the winds. Such long fetches, though, allow significant wave growth even under mild to moderate winds. The long and narrow characteristic of the bay allows winds from the south to generate their largest waves in the direction of the long axis of the bay (i.e., toward the northeast). Winds from the south occur 12% of the time and 3% of the time the winds are above 15 knots. The in-line fetches from the south to east are blocked by Dunham Island on the south side of the GIWW.

Wave growth may be limited because of the reefs, shoals, and shallow water that exist near the site. The shallow water will limit wave growth, and the reefs and shoals may dissipate waves significantly. The length of the fetches could be effectively reduced from 16 miles down to 5 miles from the southwest and west. The reefs and shoals are identified on NOS Nautical Chart 11314 "Intracoastal Waterway, Carlos Bay to Redfish Bay". An aerial photograph of the bay is provided in Figure 25. Long Reef is the only obvious subaerial reef in the area, though areas of shallow water around the site may be indicated by lighter colored water. Erosion protection of the southern end of the site and adjacent to the GIWW is recommended.

Bare-induced drawdown may adversely effect structures, such as a geotextile tube breakwater on the GIWW side of the site by creating scouring conditions. It is recommended that a study of this site be conducted to determine whether barge-induced currents will be a problem. Further, between Grass Island and Site J, and the cut on the northern side of Grass Island should be evaluated. If currents are predicted to adversely effect the cuts, Site J should be moved north about 1,000 feet to attach it to Grass Island, if feasible and acceptable. The cut on the north side of Grass Island might be filled as well.

Structures

Geotextile Tube Breakwaters

A geotextile tube breakwater will protect the southern end of the site. The tube should have an average crest elevation between of +3.0 ft to +3.5 ft MLT. This elevation is consistent with the successful elevations of the structures at PA 127A and PA 128. The alignment of the structure is depicted in Figure 25. The structure needs to extend around the end of the site to completely protect it. The structure will be between 1,500 ft and 2,000 ft long.

Articulated Concrete Mat

Along the side of the site parallel to the GIWW, an articulated concrete mat should be placed on the earthen dike similar to the mats used on the banks of the GIWW. This side of the site does not receive wind waves, but will be affected by boat wake and currents generated by vessels in the GIWW. The total length of concrete mat will be approximately 9,000 ft.

Interior Containment Dikes

Earthen containment dikes should be constructed approximately around the placement areas as shown in Figure 25. The crest elevation of the dikes will be dictated by the needs of the placement operations, but may be +7.0 ft MLT or higher. The cross-section of the dike on the western side of the site should be similar to the cross-section given for the earthen dike in Site A. The 1:10 slopes should be on the outside of the dike. The average cross-sectional area of this portion of the dike is 360 sq ft. The total length of this part of the dike is approximately 6,000 ft, so the dike will require approximately 74,500 cubic yards of borrow material.

The portion of the dike to be covered with articulated mat should have slopes as steep as possible (though not greater than that recommended for the mat) be made. Assuming the slopes are 1:3, the cross-sectional area of the dike will be approximately 300 sq ft. The length of this portion of the dike is approximately 6,000 ft. Therefore, the volume of borrow material required is 62,100. The total volume of borrow material may increase the capacity of the site and possibly reduce the final acreage by 23 acres.

The high elevation of the dike crests will be undesirable after placement and may need to be lowered.

Construction Sequence

The site should be constructed in the sequence suggested in the Section 216 Feasibility Study. The southern cell should be constructed first. The geotextile tube breakwater around the southern end of the site must be constructed. The northern end of cell may be affected by waves from the north generated across Dunham Bay or by wake generated by traffic on the GIWW. The effect would be beneficial as a more natural shoreline would develop. This side of the cell will eventually become interior to the overall site, so the period over which erosion will occur is limited.

The dredged material discharge and highest elevations in the cells will be on the channel side and northern end of the site. Placing the material in these locations will be easier for the dredging contractor because they are closer to the dredge.

After placement is complete, the dikes should be lowered to at about 2.5 ft MLT.

Site K (Dunham Island, East of GIWW)

General Location

Site K is located on the south side of the GIWW at the southwest tip of Dunham Island near station 840+000. The site will provide about 25 acres of new marsh. The acreage estimated in the Section 216 Feasibility Study was 35 acres, but that assumes a 3.1 ft thickness of placed material. Because the average bed elevation at this site is -1.8 ft MLT and the average elevation of the marsh surface required is +2.5 ft MLT, a 4.3 ft thickness of material is needed. Therefore, only 25 acres of the proposed 35 acres can be developed.

Leave it 35 acres Dredging quantities increased

Wave Exposure and Recommended Layout

The site is exposed to long fetches ranging up to 16 miles from the southwest (Table 1). Winds are mild and infrequent from this direction. Table two indicates that winds from the southwest and west occur only 4 % of the time. Such long fetches, though, allow significant wave growth even under mild to moderate winds. Wave growth may be limited because of the reefs, shoals, and shallow water that exist near the site. The shallow water will limit wave growth, and the reefs and shoals may dissipate wave energy, particularly Long Reef which appears to effectively reduce the length of the fetches from 16 miles down to 4 miles from the southwest. The reefs and shoals are identified on NOS Nautical Chart 11314 "Intracoastal Waterway, Carlos Bay to Redfish Bay". An aerial photograph of the bay is provided in Figure 26 where Long Reef is evident with much of it subaerial.

The fetches from the south to east are much shorter and range between 1 - 2 miles. Winds from these directions occur nearly 65% of the time and 16% of the time they have magnitudes greater than 15 knots. The short fetches, though, make these winds less problematic.

Assuming that the reef provides wave dissipation and that winds are generally low-magnitude from the southwest and west, a sand-filled geotextile tube breakwater is recommended for erosion protection. (Recall the success of the geotextile tubes at PA 128 which has fetches up to

14 miles long oriented toward the east which has strong and more frequent winds than the west.) The tubes are only needed on the sides exposed to Aransas Bay. On the side adjacent to Dunham island, an earthen dike should be used. The orientation of the site should be modified as shown in Figure 24 such that one corner of the site should be in the lee of the Pelican Reef. The acreage that is lost on the west end of the site by reconfiguring it nearly accounts for the reduced acreage expected because of water depths.

On the east end of the site, the tube structure should taper back toward the island. Terminating about 300 ft offshore of the island. The east side of the tube structure should be segmented with gaps about 10-25 ft wide. The gaps would provide variation in erosion patterns behind the tubes, enhance tidal exchange, and increase access.

Structures

Offshore Breakwater

A geotextile-tube breakwater is recommended around the perimeter of Site K. The crest elevation of the structure should be between +3 ft and + 3.5 ft MLT. As shown in Figure 27, the structure on the west side of the site, will begin about 300 ft from shore and extend south approximately 700 ft. The structure will then run east an additional 2,300 ft. The structure will then angle back toward the shoreline 1,000 ft and terminate about 300 ft from the shore. The structure on this side of the site should be segmented with 200 ft - 250 ft segments and gaps 10 ft to 25 ft wide. The total length of the structure will be approximately 4,000 ft.

Earthen Dikes

An earthen dike should be constructed at least 100 ft behind the geotextile tube structure to enhance tidal exchange and access to the site. The dike design discussed for Site A should be used here where the exterior slope up to elevation +2.5 ft MLT is 1:10 and all other slopes are made as steep as possible. The cross-sectional area of the dike will be 385 sq ft. The total length of dike required will be approximately 5,300 ft. Therefore, approximately 70,000 cubic yards of borrow material will be needed. This will increase the capacity of the site and may reduce the final marsh area by 11 acres.

Shoreline protection

The end of Dunham Island should be protected from erosion by carrying the articulated mat revetment used along the GIWW around the point. The revetment should terminate about 300 ft beyond the point where the geotextile tube would intersect the island if it were extended.

Construction Sequence

This site is scheduled for construction in the first dredging cycle of the DMMP. The dredge discharge pipe will be located on the west end. The west end will be highest and toward Dunham Island. The site will grade to lower elevations toward the east end and the bay.

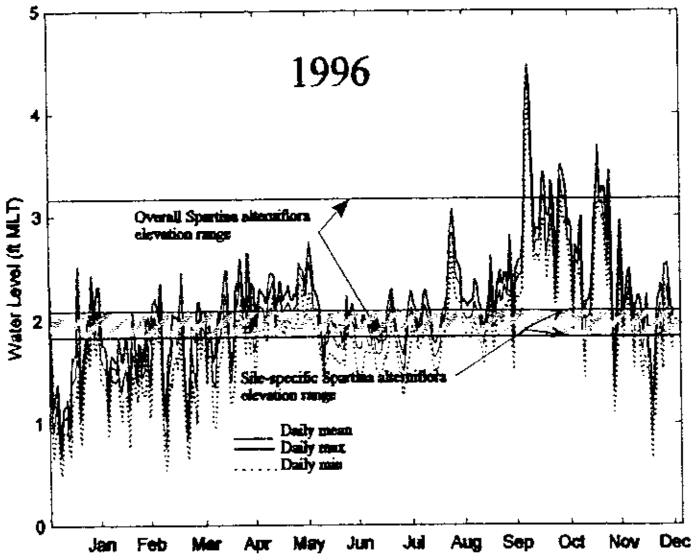


Figure 1. Elevation range found for S. alterniflora over all the surveyed sites and for a specific site at Welder Flat. (See grid #2).

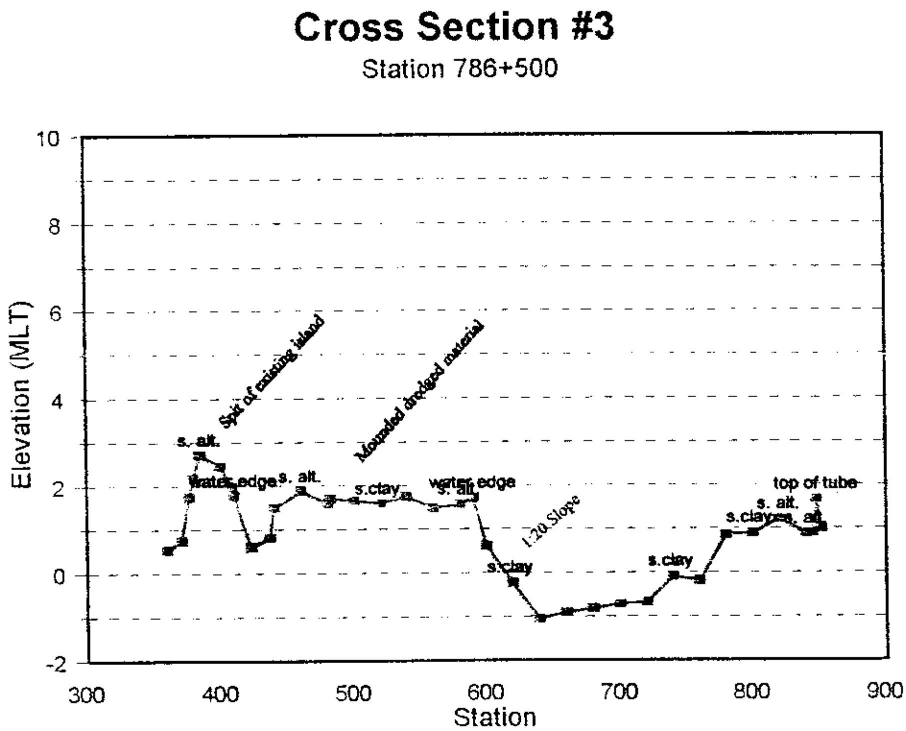
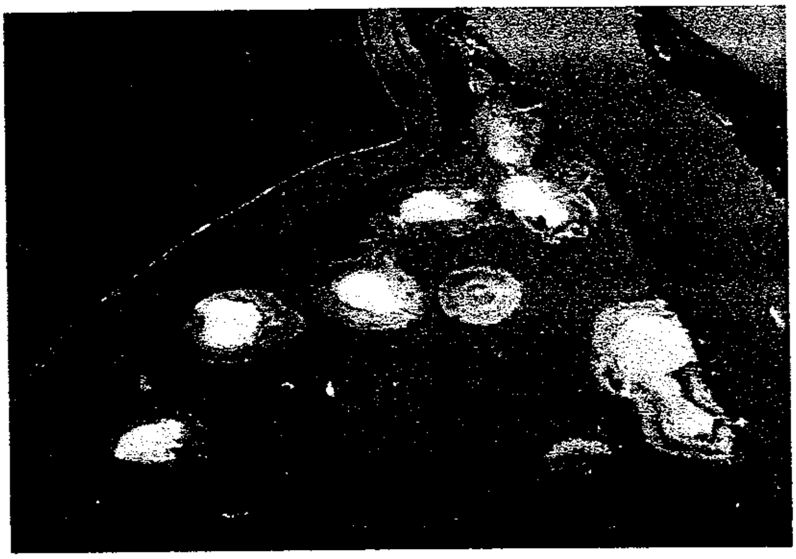


Figure 3. Cross sectional survey near north end of PA 128.



a)

b)

Figure 3. a) placement of coarse grained material forms steeply sloping circular mounds, b) placement of fine-grained material forms broad, and flat or mildly sloping mounds.

Figure 6. 1995 view of PA 127A. The breakwater curves out from the shoreline of False Live Oak Island (PA 127). Behind the breakwater is an earthen containment dike. Dredged material was placed in the containment area.

Figure 7. Northern tube at PA 128 in May 1995. The project was constructed in Summer of 1993.

Figure 8. Articulated concrete mat at the North end of MEC #1.

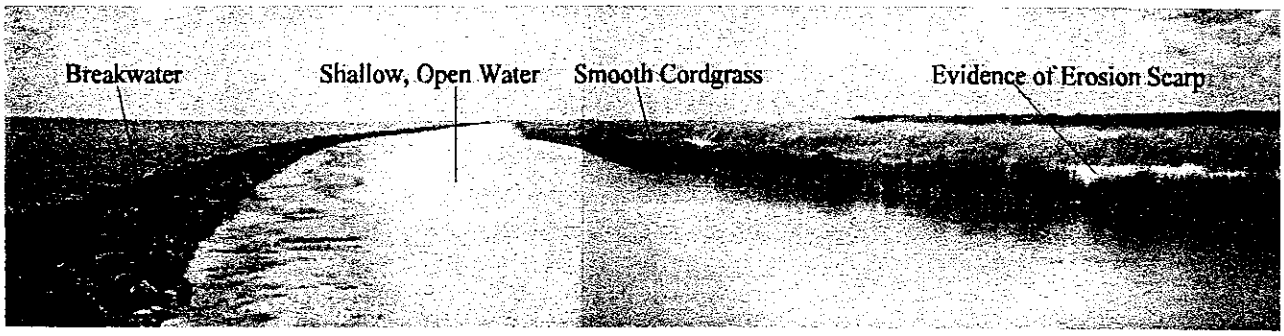


Figure 9. Configuration of structures at PA127A.

Figure 10. View of geotextile tubes at PA 128.

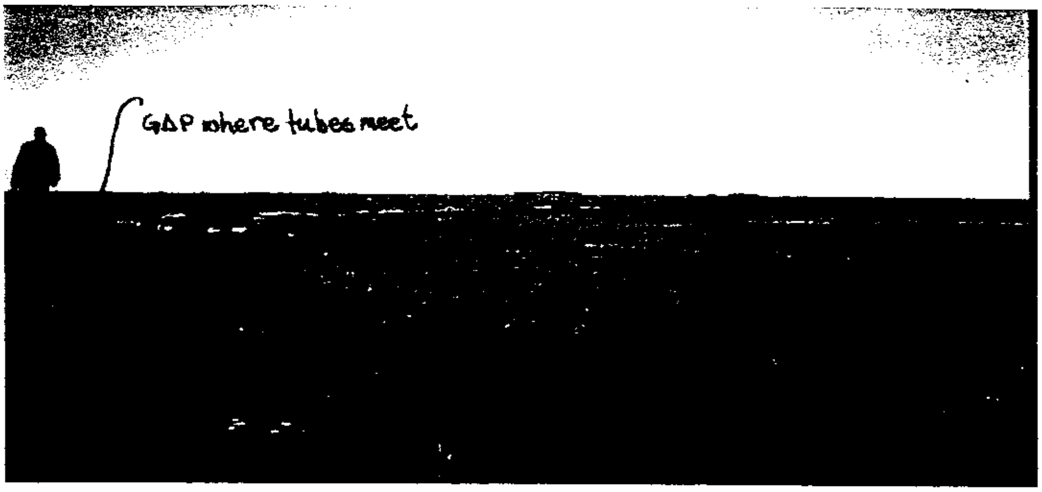


Figure 11. North tube at PA 128 in April 1994. Plants were sprigged sometime in the late summer or fall of 1993.

Figure 12. Mitchell Energy Corporation wetland creation projects near Bludworth Island. Only sites MEC #1 & #2 are shown.

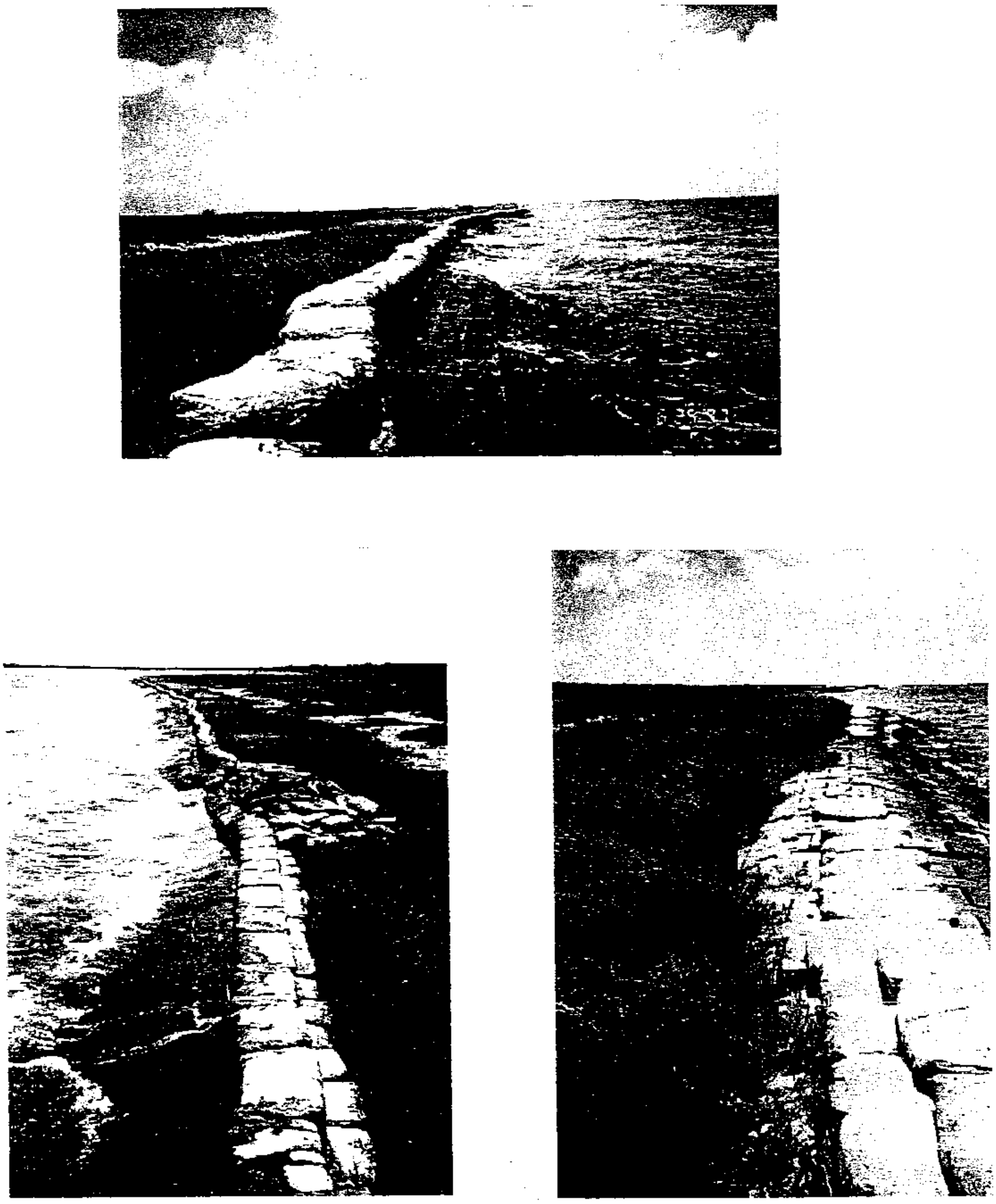
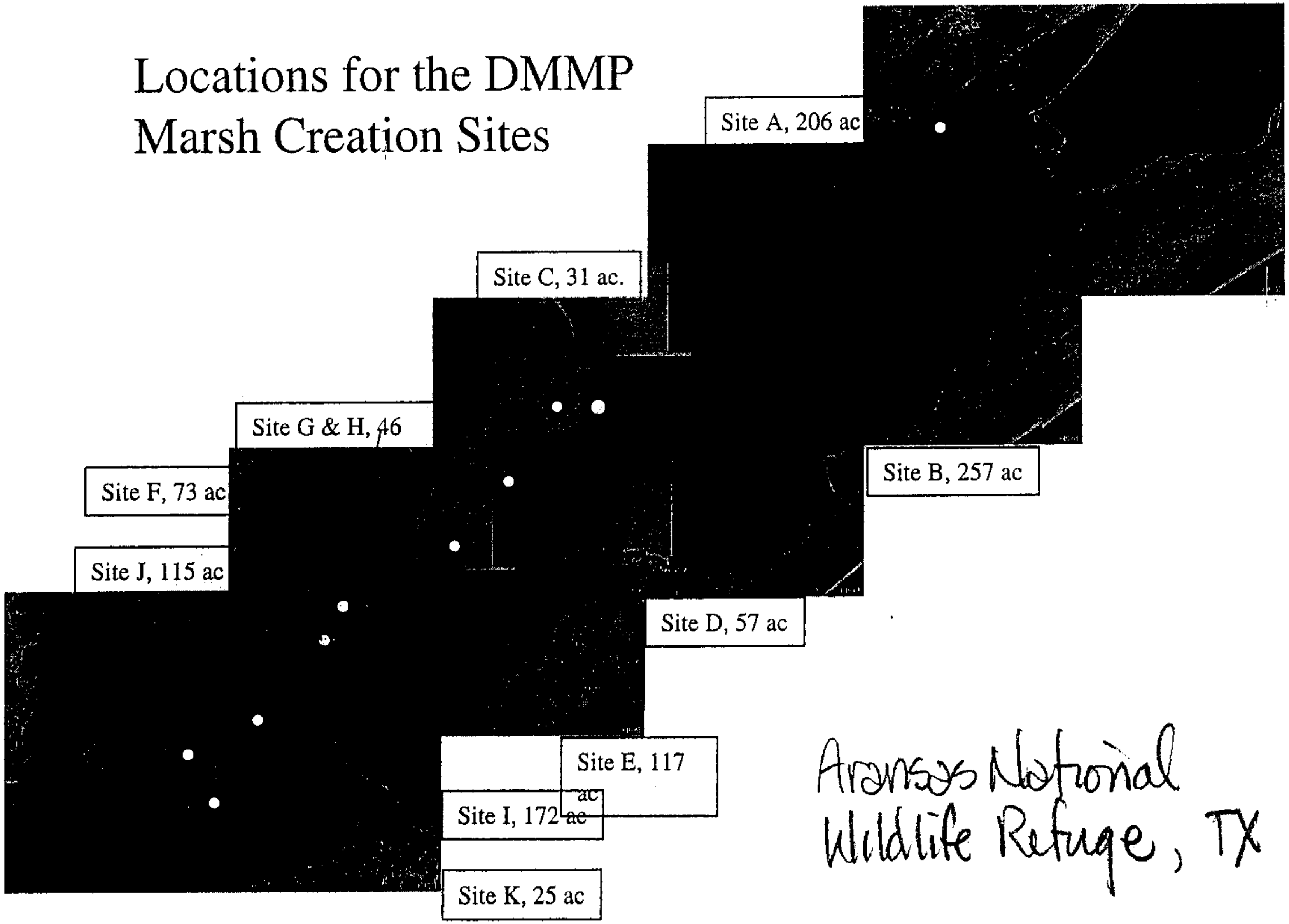


Figure 13. Articulated concrete mat with hardened bags of concrete placed on top to raise the dike elevation

Figure 16. Dike on the east-facing side of site MEC #3.

Figure 17. Dike on the east-facing side of site MEC #2.

Locations for the DMMP Marsh Creation Sites



Aransas National Wildlife Refuge, TX

Fig 14

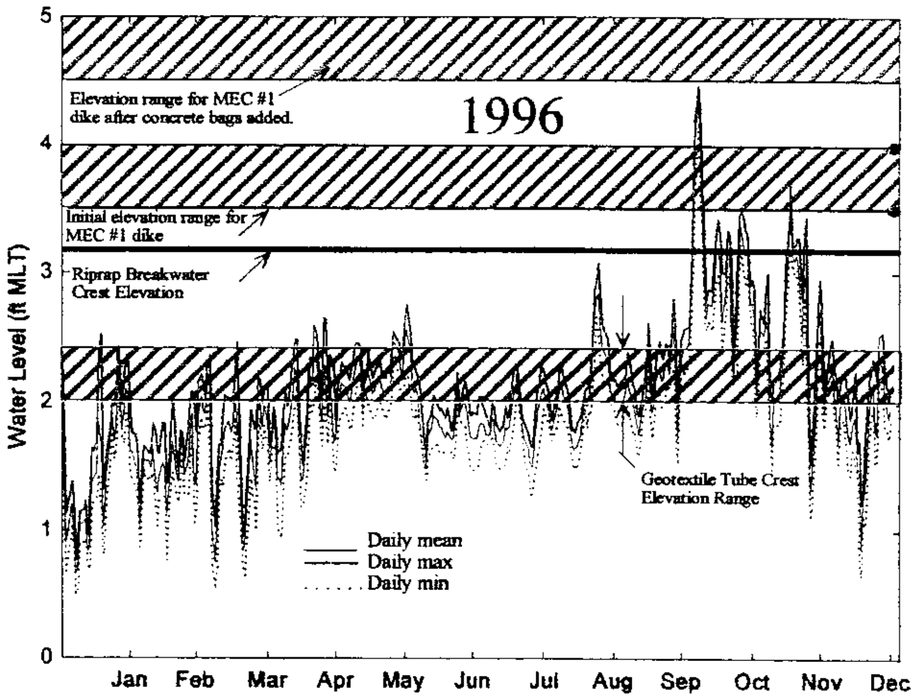


Figure 18. Comparison of structure elevations to 1996 water levels in the area around the ANWR.

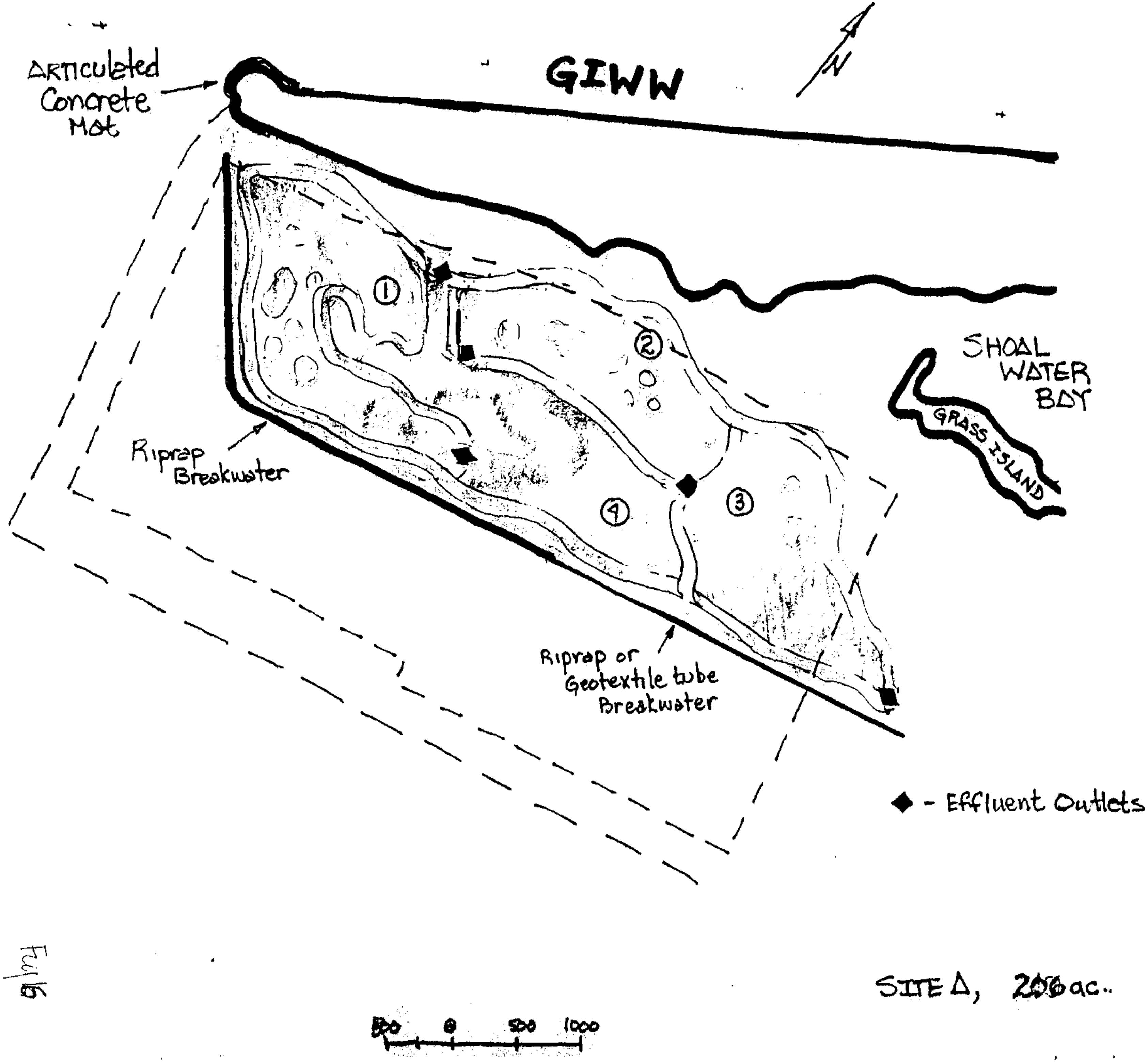
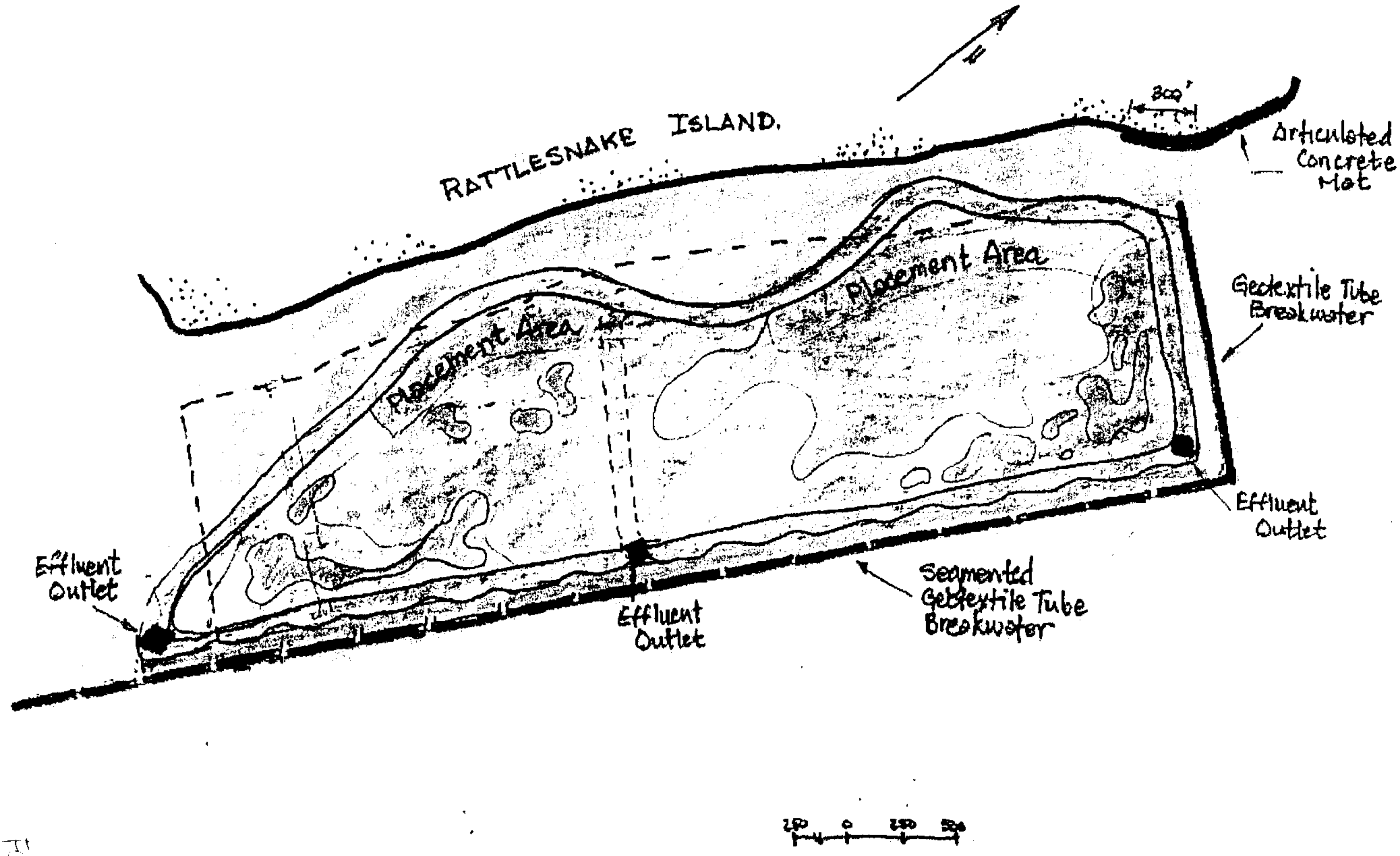
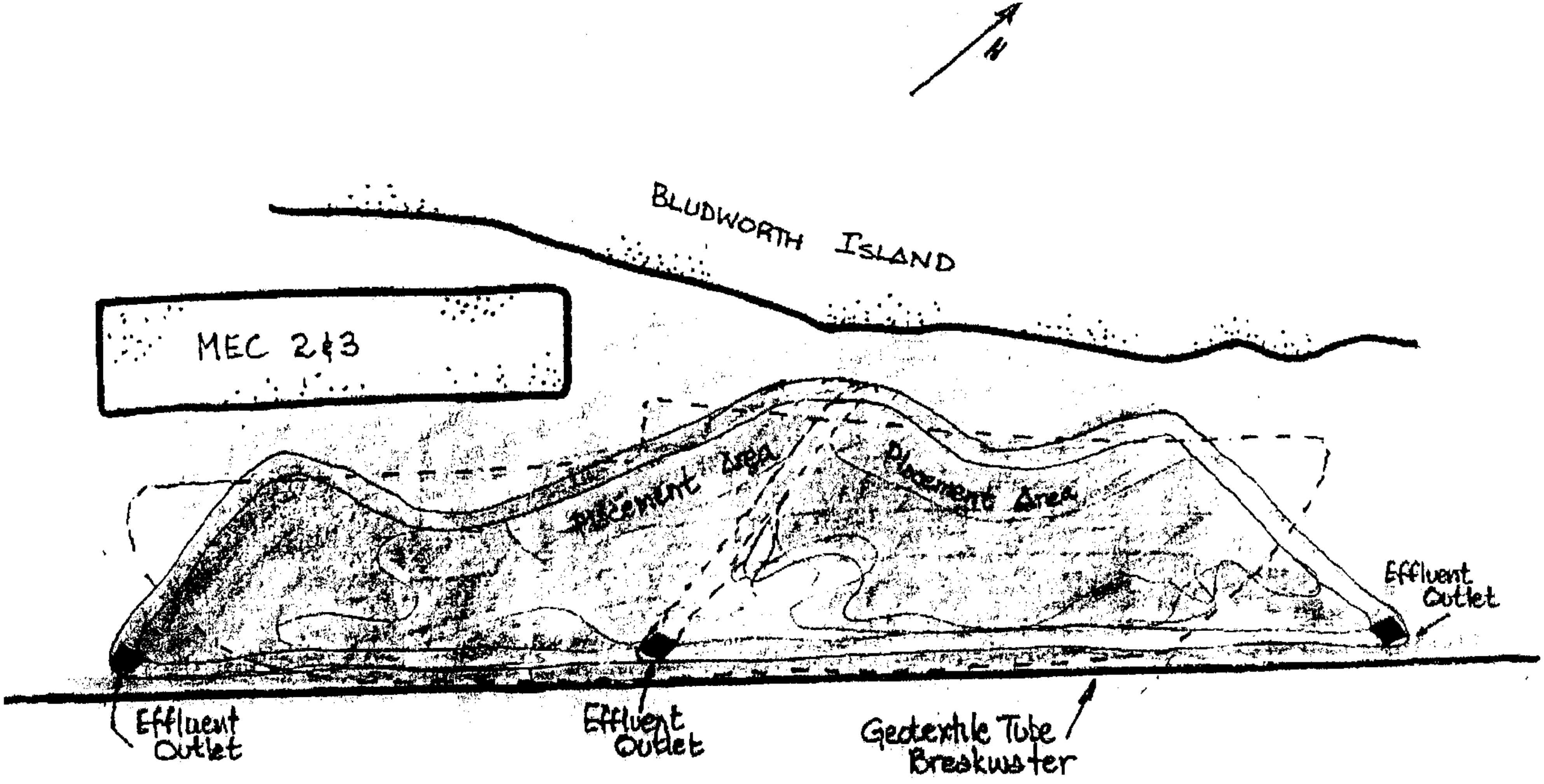

GIWW
N
Articulated Concrete Mat
Riprap Breakwater
Riprap or Geotextile tube Breakwater
SHOAL WATER BAY
GRASS ISLAND
1
2
3
4
◆ - Effluent Outlets
SITE Δ, 200 ac.
500 0 500 1000

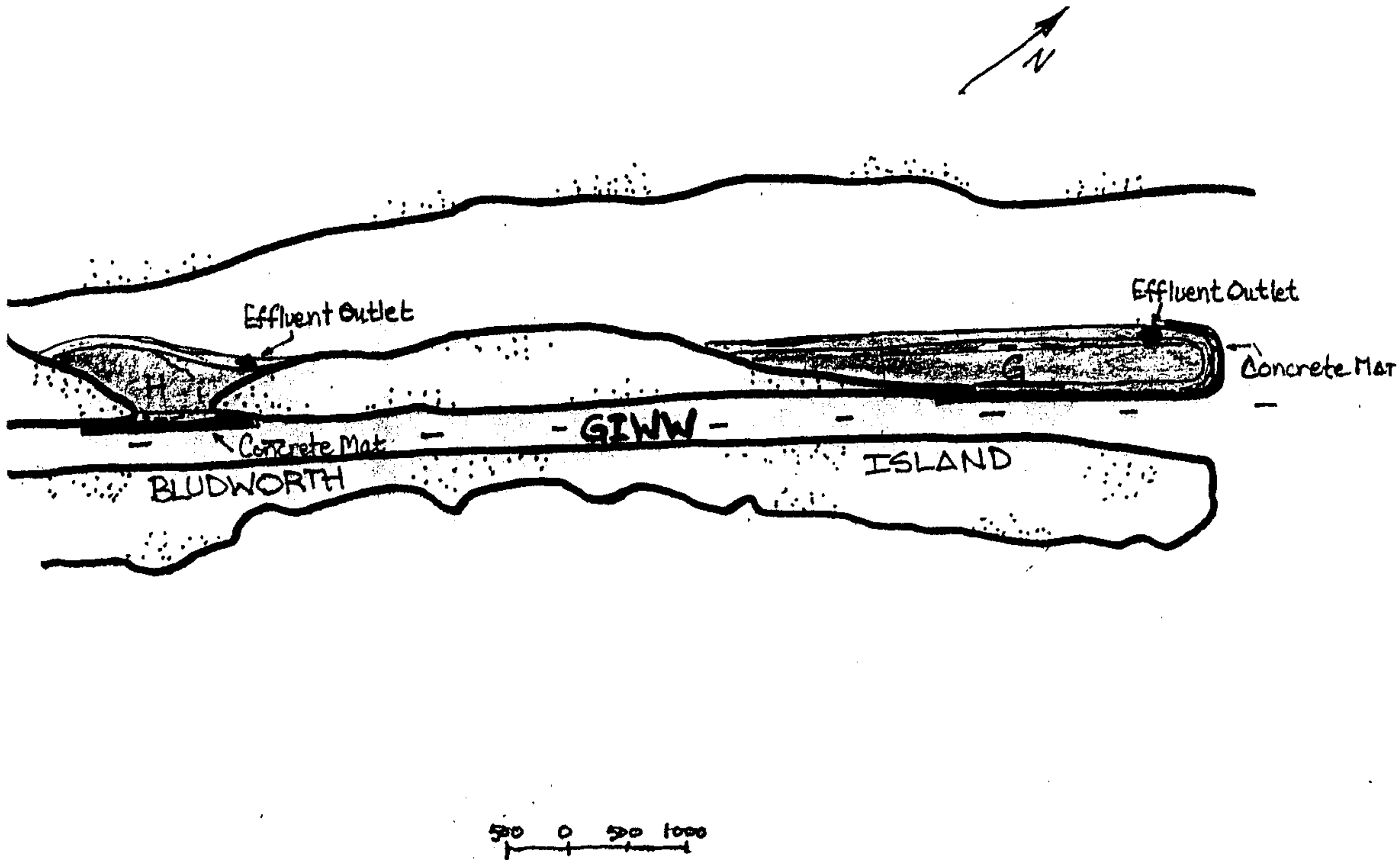
Fig 16



117
SITE E, ~~124~~ac

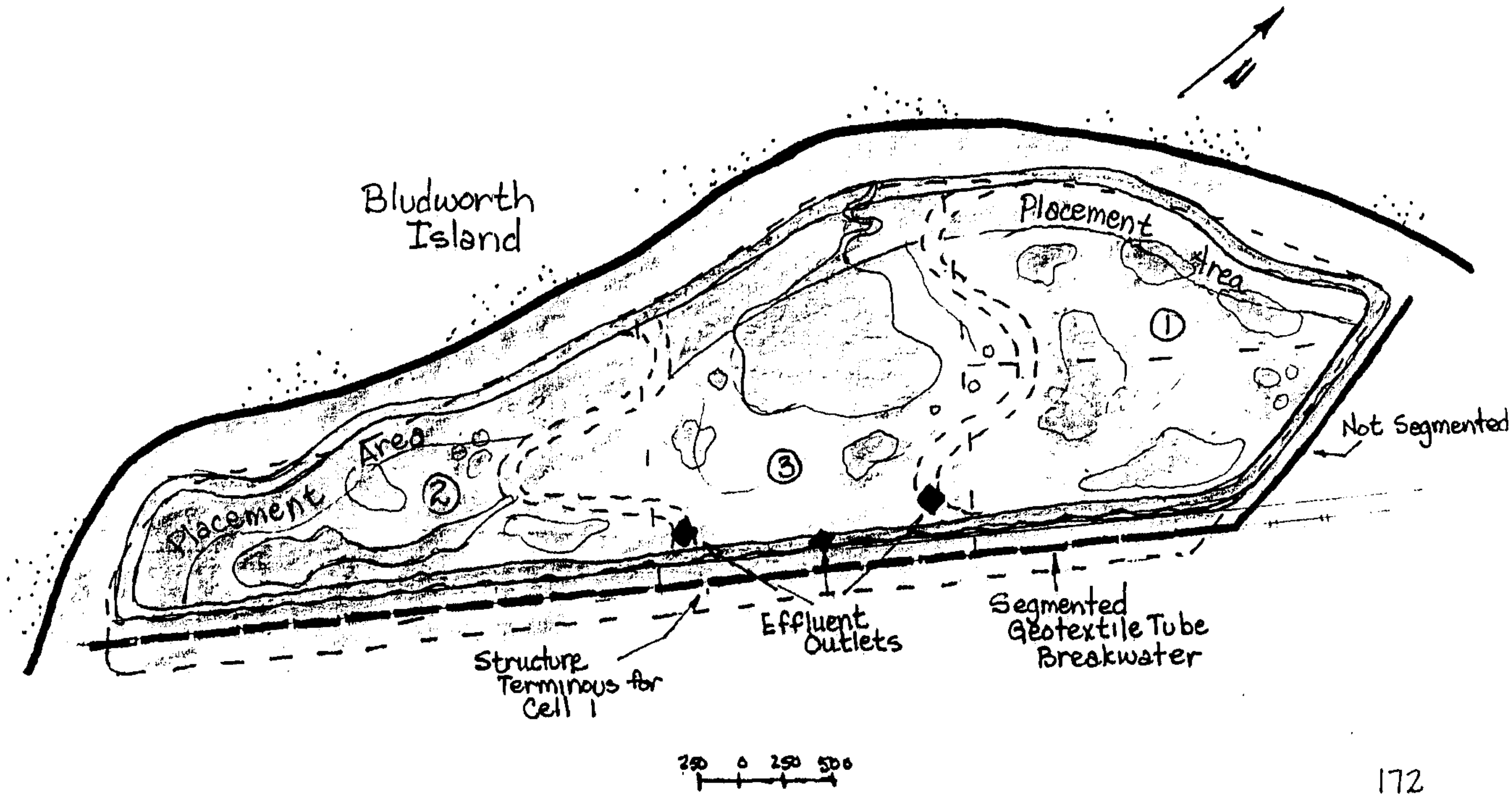


SITE F, 77ac. 73



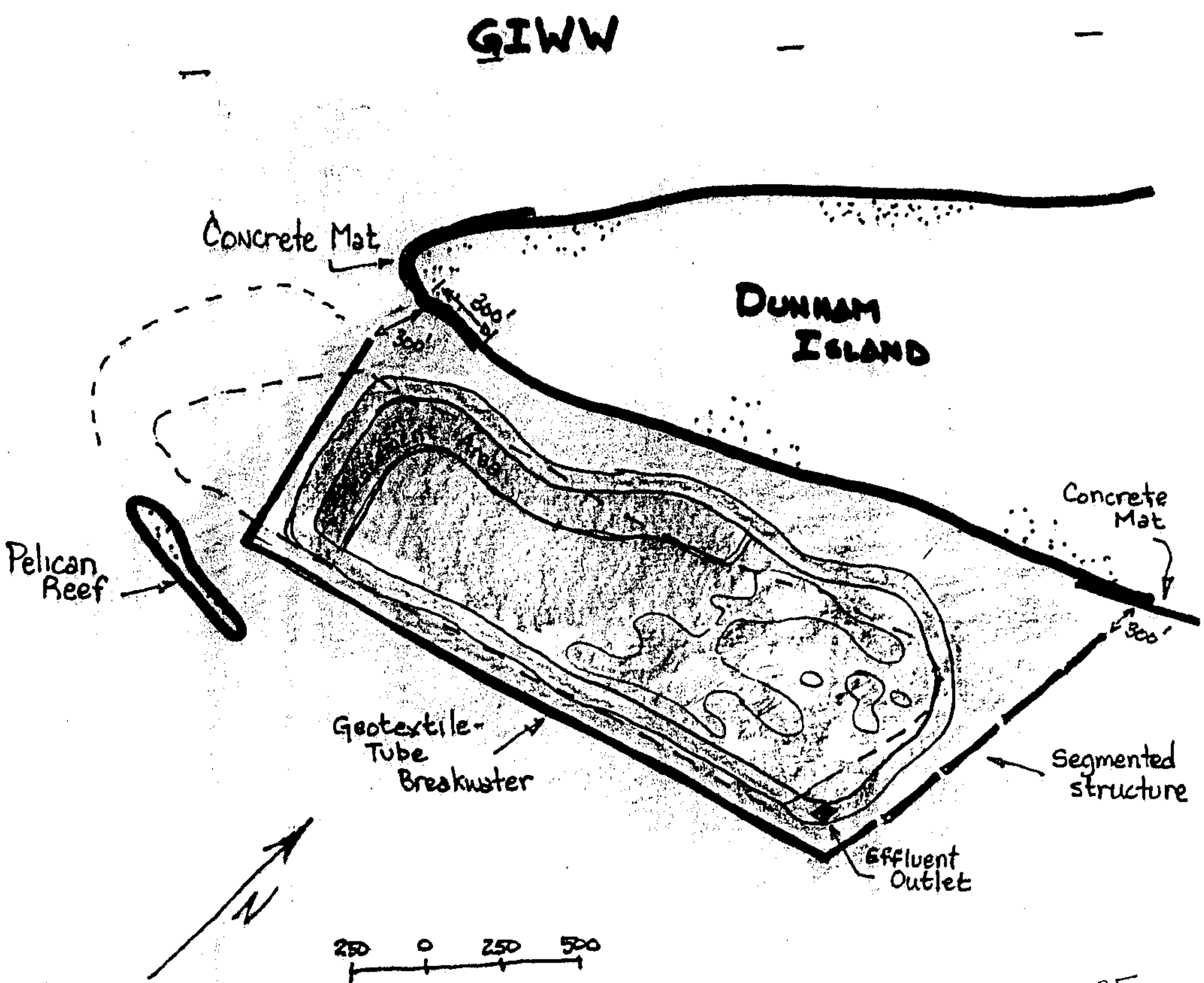
SITE G & H
~~32 & 17~~ ac., respectively
30 & 16 ac.

Fig 23



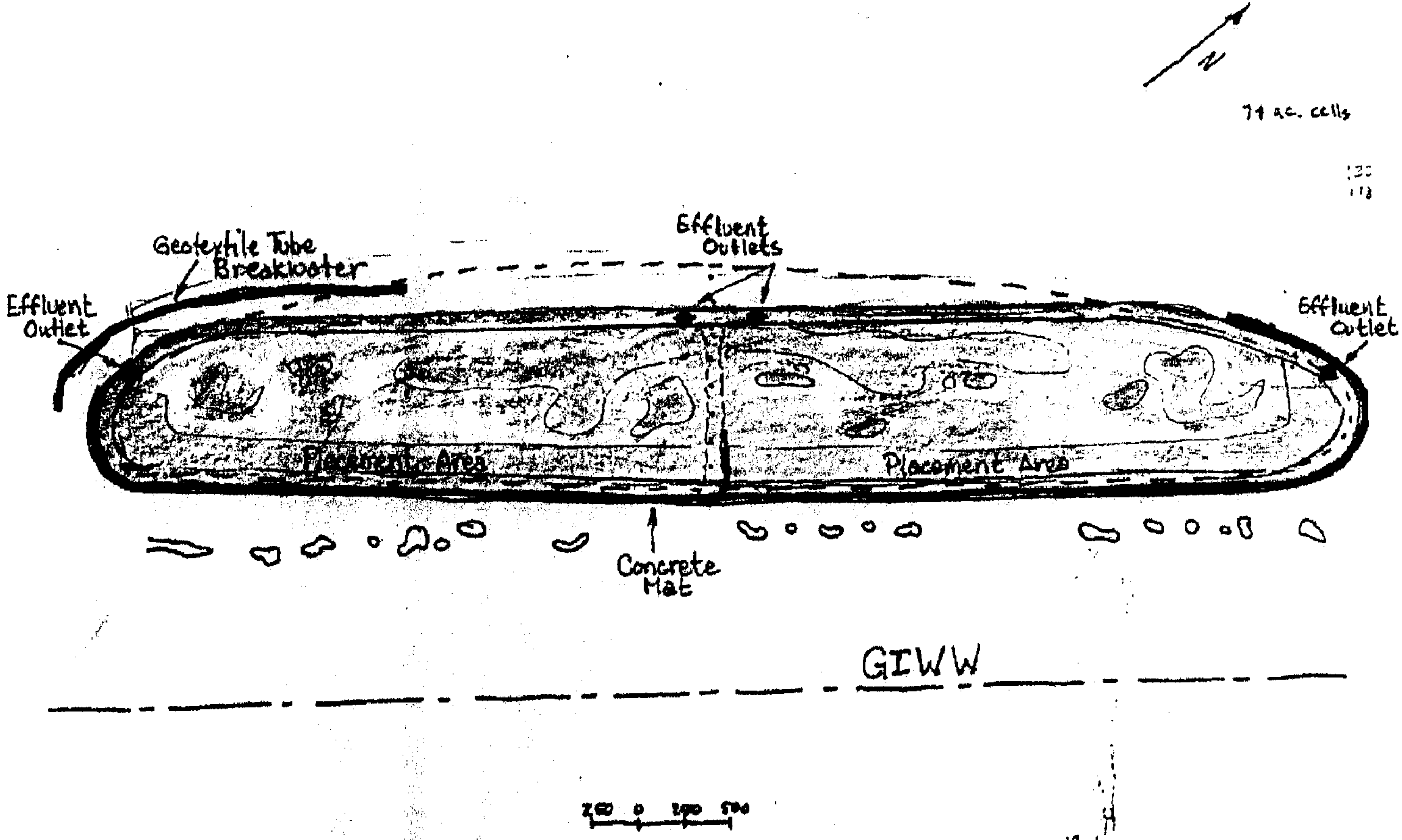
SITE I, ~~183~~ 172 ac.

Fig 24



SITE K, ~~27~~ 25 ac.

Fig 27



SITE J, 115 ~~122~~ ac.

Fig 25

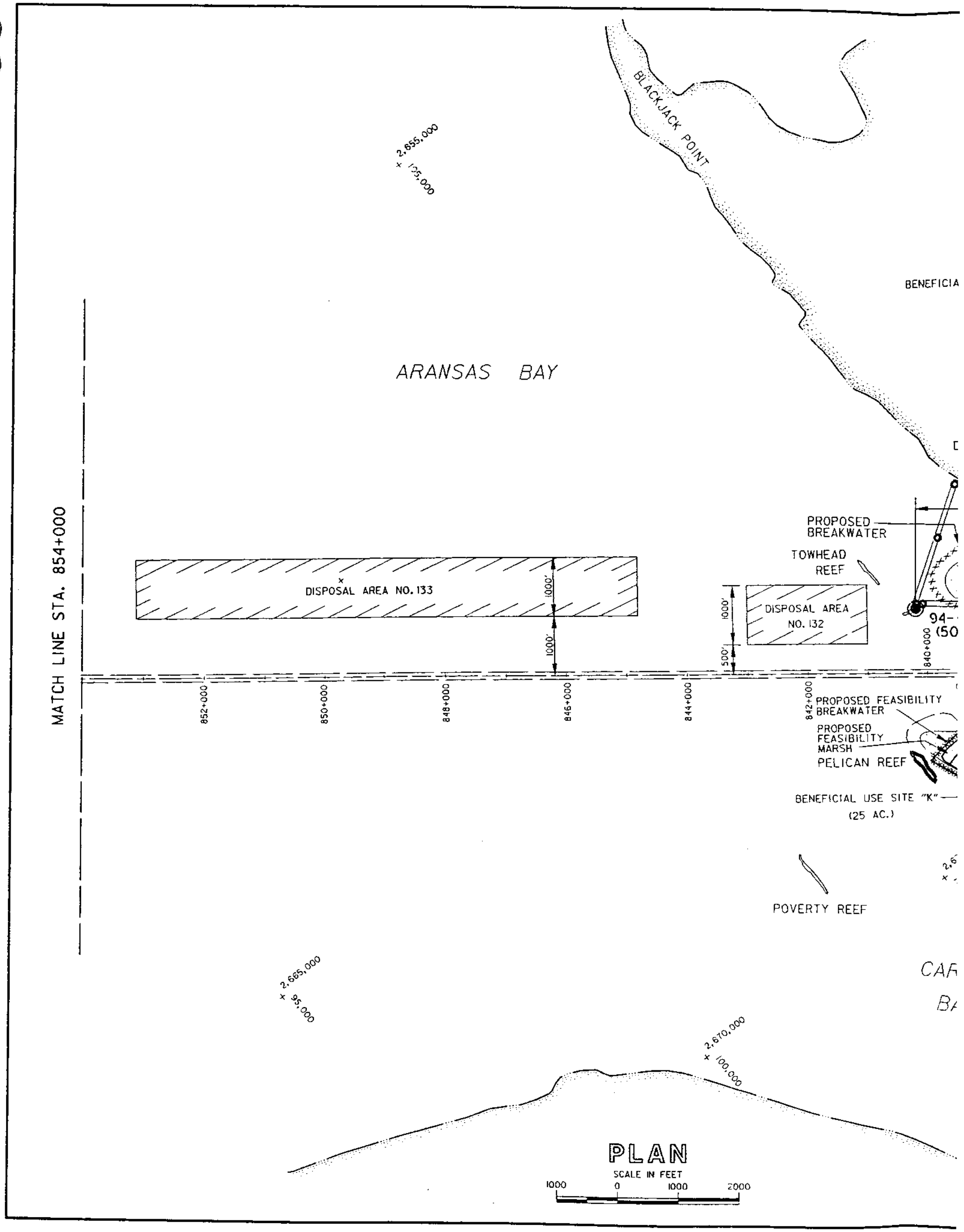
Gulf Intracoastal Waterway
Aransas National Wildlife Refuge
Dredged Material Management Plan

Appendix C

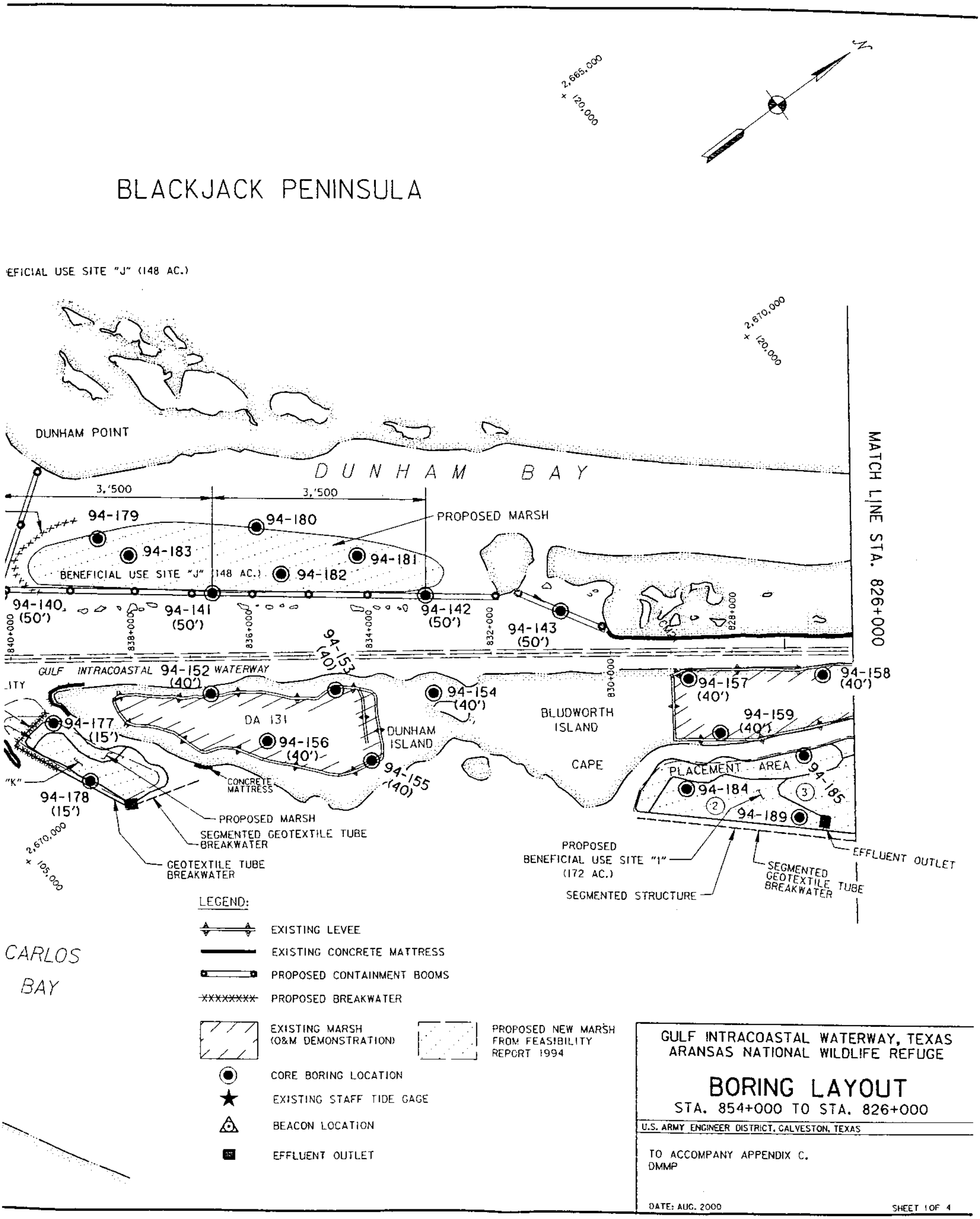
Geotechnical Design

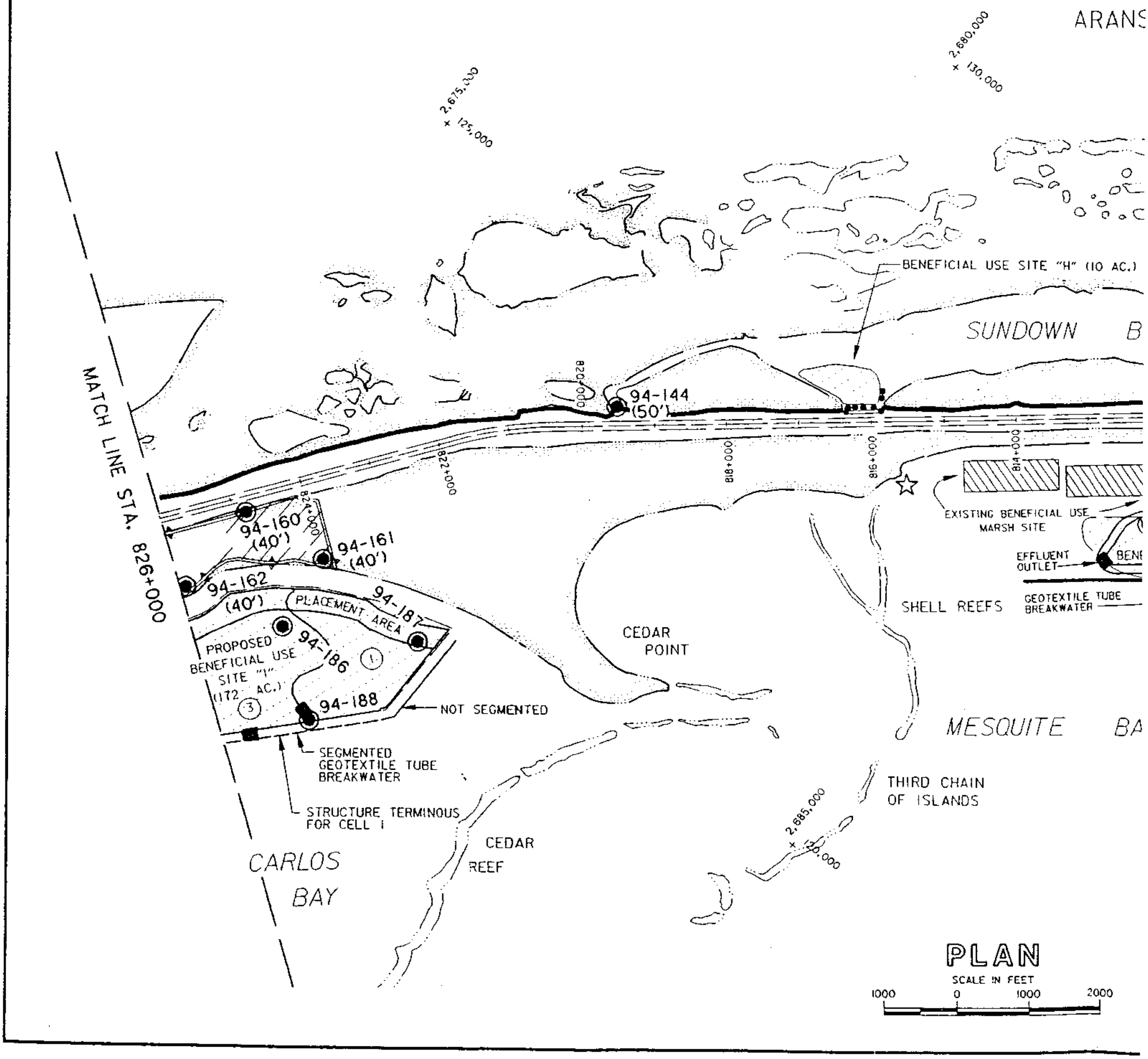
Exhibit C-1

Boring Layout

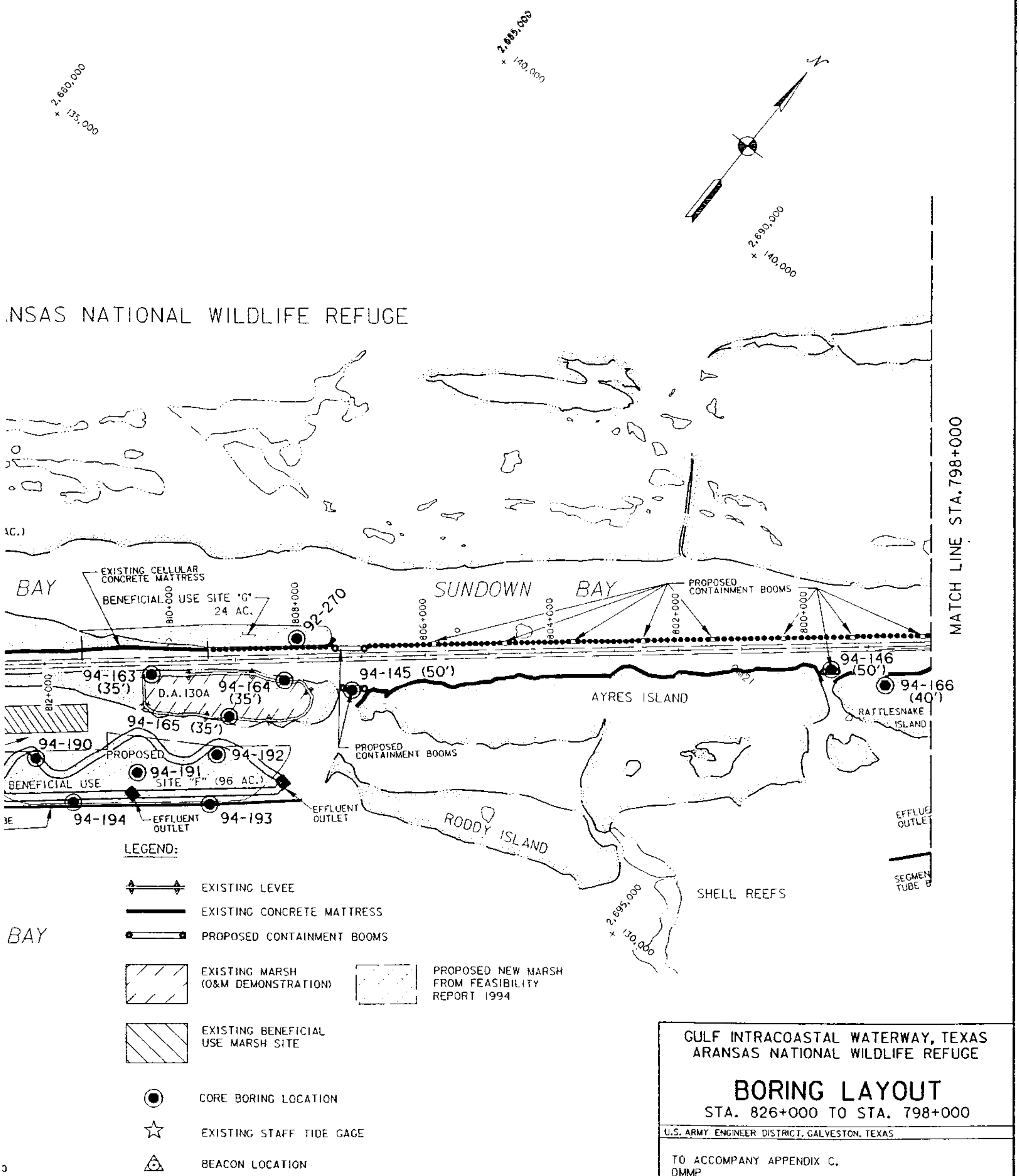


BLACKJACK POINT
2,655,000
× 105,000
BENEFICIA
ARANSAS BAY
MATCH LINE STA. 854+000
PROPOSED
BREAKWATER
TOWHEAD
REEF
DISPOSAL AREA NO. 133
1000'
1000'
DISPOSAL AREA
NO. 132
1000'
500'
94-
(50
840+000
852+000
850+000
848+000
846+000
844+000
842+000
PROPOSED FEASIBILITY
BREAKWATER
PROPOSED
FEASIBILITY
MARSH
PELICAN REEF
BENEFICIAL USE SITE "K"
(25 AC.)
POVERTY REEF
CAR
BA
2,665,000
× 95,000
2,670,000
× 100,000
PLAN
SCALE IN FEET
1000
0
1000
2000


BLACKJACK PENINSULA
2,665,000
120,000
N
EFICIAL USE SITE "J" (148 AC.)
2,670,000
120,000
DUNHAM POINT
D U N H A M B A Y
MATCH LINE STA. 826+000
3,'500
3,'500
PROPOSED MARSH
94-179
94-180
94-183
94-181
BENEFICIAL USE SITE "J" (148 AC.)
94-182
94-140, (50')
94-141 (50')
94-142 (50')
94-143 (50')
840+000
838+000
836+000
834+000
832+000
830+000
828+000
GULF INTRACOASTAL WATERWAY
94-152 (40')
94-153 (40)
94-154 (40')
94-157 (40')
94-158 (40')
94-159 (40')
DA 131
94-156 (40')
DUNHAM ISLAND
BLUDWORTH ISLAND
CAPE
94-155 (40)
94-177 (15')
94-178 (15')
"K"
CONCRETE MATTRESS
PLACEMENT AREA
94-184
94-185
94-189
2
3
PROPOSED MARSH
SEGMENTED GEOTEXTILE TUBE BREAKWATER
GEOTEXTILE TUBE BREAKWATER
2,670,000
105,000
PROPOSED BENEFICIAL USE SITE "I" (172 AC.)
SEGMENTED STRUCTURE
EFFLUENT OUTLET
SEGMENTED GEOTEXTILE TUBE BREAKWATER
CARLOS BAY
LEGEND:
EXISTING LEVEE
EXISTING CONCRETE MATTRESS
PROPOSED CONTAINMENT BOOMS
PROPOSED BREAKWATER
EXISTING MARSH (O&M DEMONSTRATION)
PROPOSED NEW MARSH FROM FEASIBILITY REPORT 1994
CORE BORING LOCATION
EXISTING STAFF TIDE GAGE
BEACON LOCATION
EFFLUENT OUTLET
GULF INTRACOASTAL WATERWAY, TEXAS
ARANSAS NATIONAL WILDLIFE REFUGE
BORING LAYOUT
STA. 854+000 TO STA. 826+000
U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS
TO ACCOMPANY APPENDIX C.
DMMP
DATE: AUG. 2000
SHEET 1 OF 4



ARANS
BENEFICIAL USE SITE "H" (10 AC.)
SUNDOWN B
94-144
(50')
MATCH LINE STA. 826+000
94-160
(40')
94-161
(40')
94-162
(40')
PLACEMENT AREA
94-187
PROPOSED BENEFICIAL USE SITE "I" (172 AC.)
94-186
94-188
NOT SEGMENTED
SEGMENTED GEOTEXTILE TUBE BREAKWATER
STRUCTURE TERMINOUS FOR CELL I
CARLOS BAY
CEDAR REEF
CEDAR POINT
EXISTING BENEFICIAL USE MARSH SITE
EFFLUENT OUTLET
GEOTEXTILE TUBE BREAKWATER
SHELL REEFS
MESQUITE BA
THIRD CHAIN OF ISLANDS
PLAN
SCALE IN FEET
1000 0 1000 2000



GULF INTRACOASTAL WATERWAY, TEXAS
ARANSAS NATIONAL WILDLIFE REFUGE

BORING LAYOUT

STA. 826+000 TO STA. 798+000

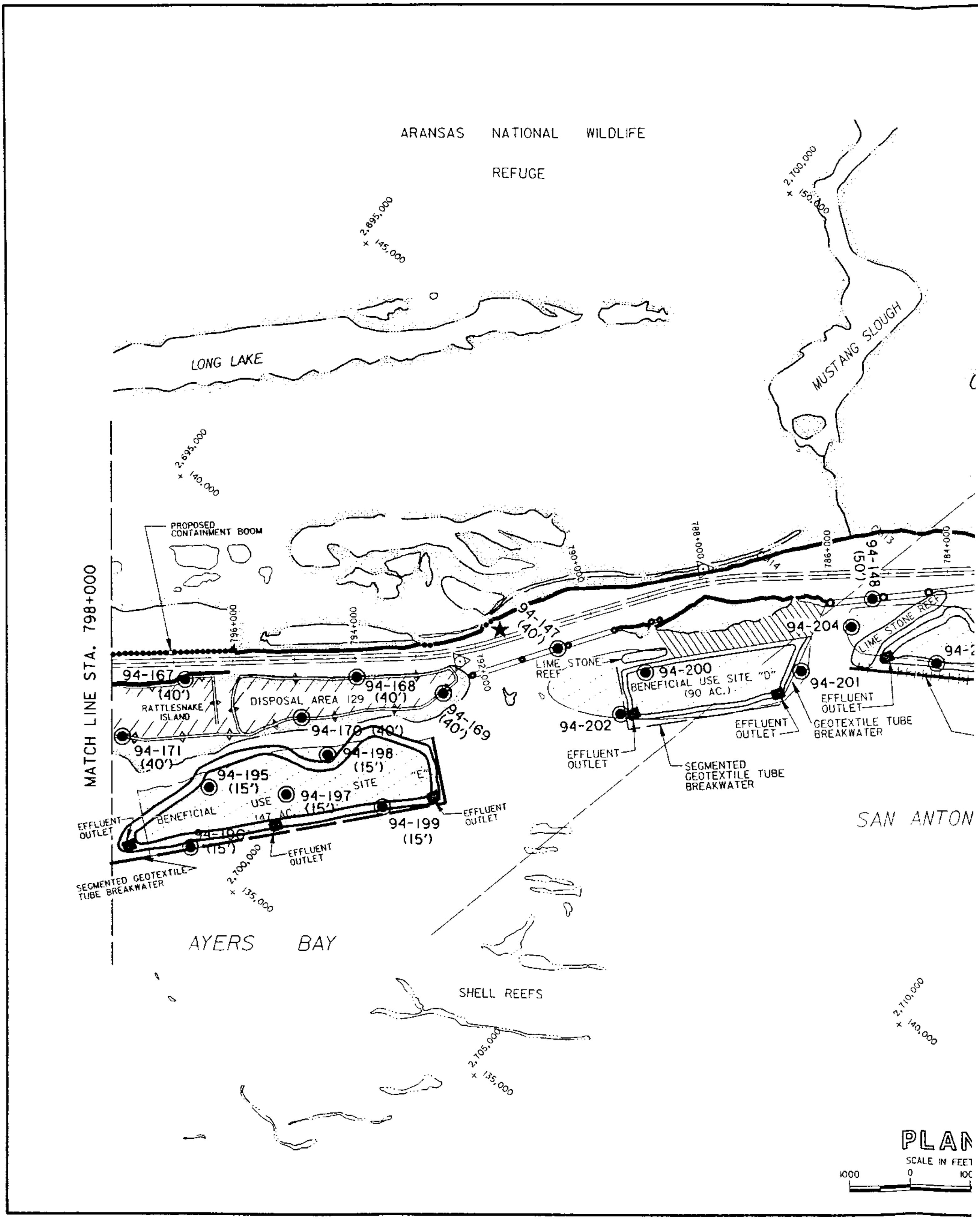
U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS

TO ACCOMPANY APPENDIX C, DMMP

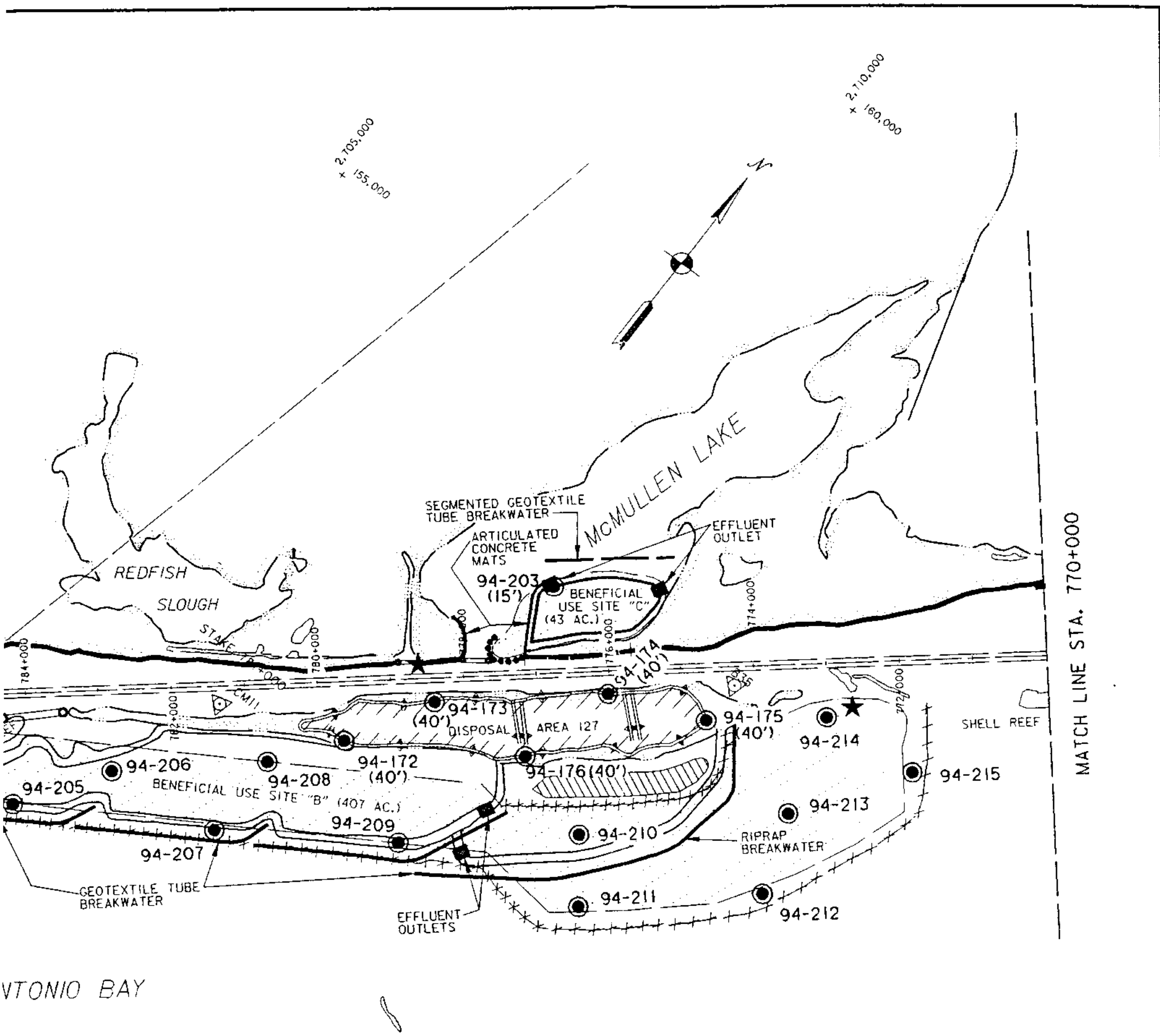
DATE: AUG. 2000

SHEET 2 OF 4

EXHIBIT C-1 SHT. 2



ARANSAS NATIONAL WILDLIFE
REFUGE
LONG LAKE
MUSTANG SLOUGH
MATCH LINE STA. 798+000
PROPOSED CONTAINMENT BOOM
94-167 (40')
RATTLESNAKE ISLAND
DISPOSAL AREA 129
94-168 (40')
94-169 (40')
94-170 (40')
94-171 (40')
94-147 (40')
LIME STONE REEF
94-195 (15')
94-196 (15')
94-197 (15')
94-198 (15')
94-199 (15')
BENEFICIAL USE SITE "E" 147 AC.
EFFLUENT OUTLET
SEGMENTED GEOTEXTILE TUBE BREAKWATER
94-200
BENEFICIAL USE SITE "D" (90 AC.)
94-201
94-202
94-204
94-148 (50')
GEOTEXTILE TUBE BREAKWATER
SEGMENTED GEOTEXTILE TUBE BREAKWATER
LIME STONE REEF
SAN ANTON
AYERS BAY
SHELL REEFS
PLAN
SCALE IN FEET



LEGEND

- EXISTING CELLULAR CONCRETE MATTRESS
- PROPOSED CONCRETE MATTRESS
- PROPOSED GROUT TUBES
- PROPOSED CONTAINMENT BOOMS
- XXXXXXXX PROPOSED BREAKWATER
- ~~XXXXXXXX~~ EXISTING BREAKWATER
- EXISTING MARSH (O&M DEMONSTRATION)
- PROPOSED NEW MARSH
- CORE BORING LOCATION
- ★ EXISTING STAFF TIDE GAGE
- BEACON LOCATION

LAN

LE IN FEET

1000 2000

GULF INTRACOASTAL WATERWAY, TEXAS
ARANSAS NATIONAL WILDLIFE REFUGE

BORING LAYOUT

STA. 798+000 TO STA. 770+000

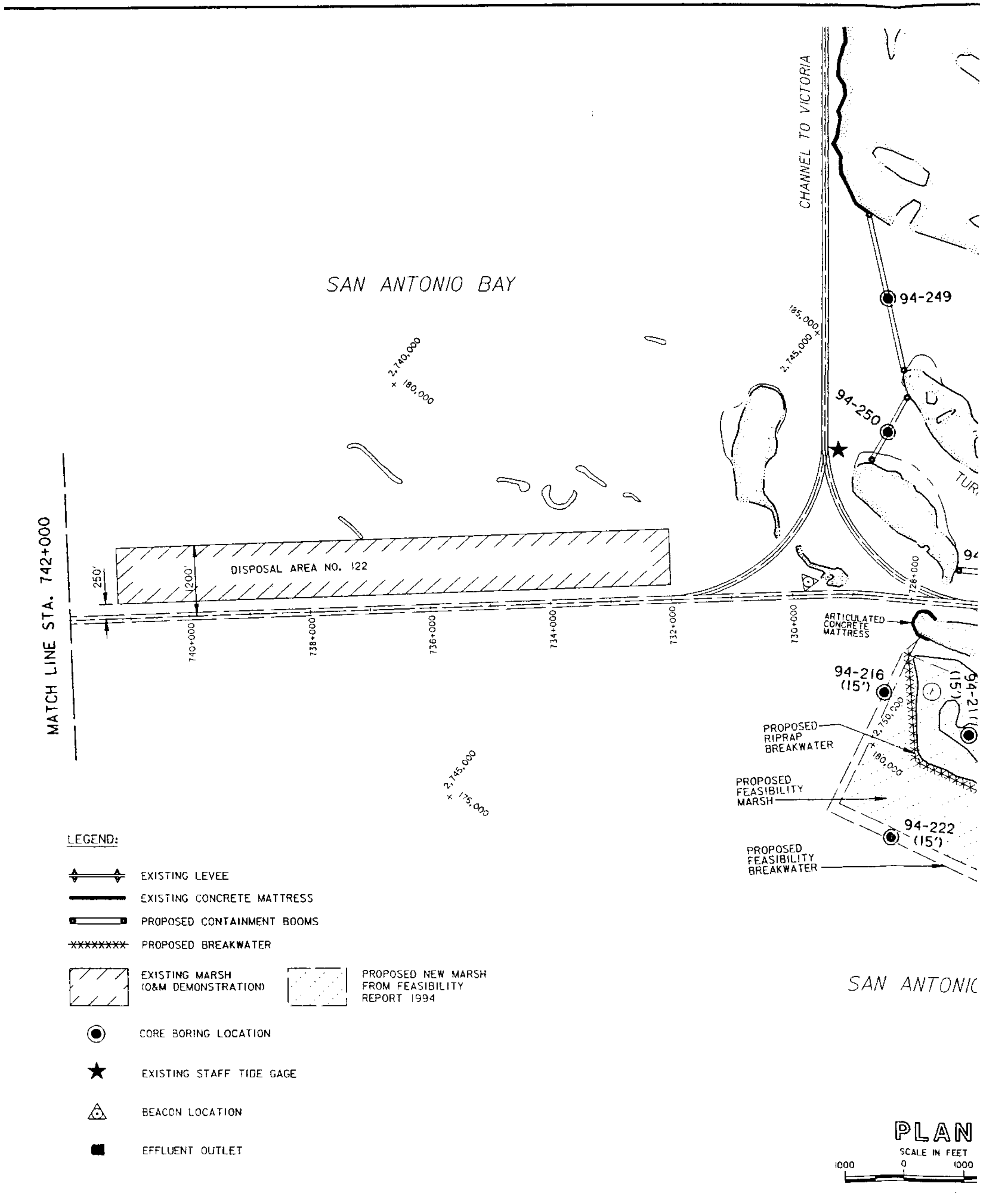
U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS

TO ACCOMPANY APPENDIX C, DMMP

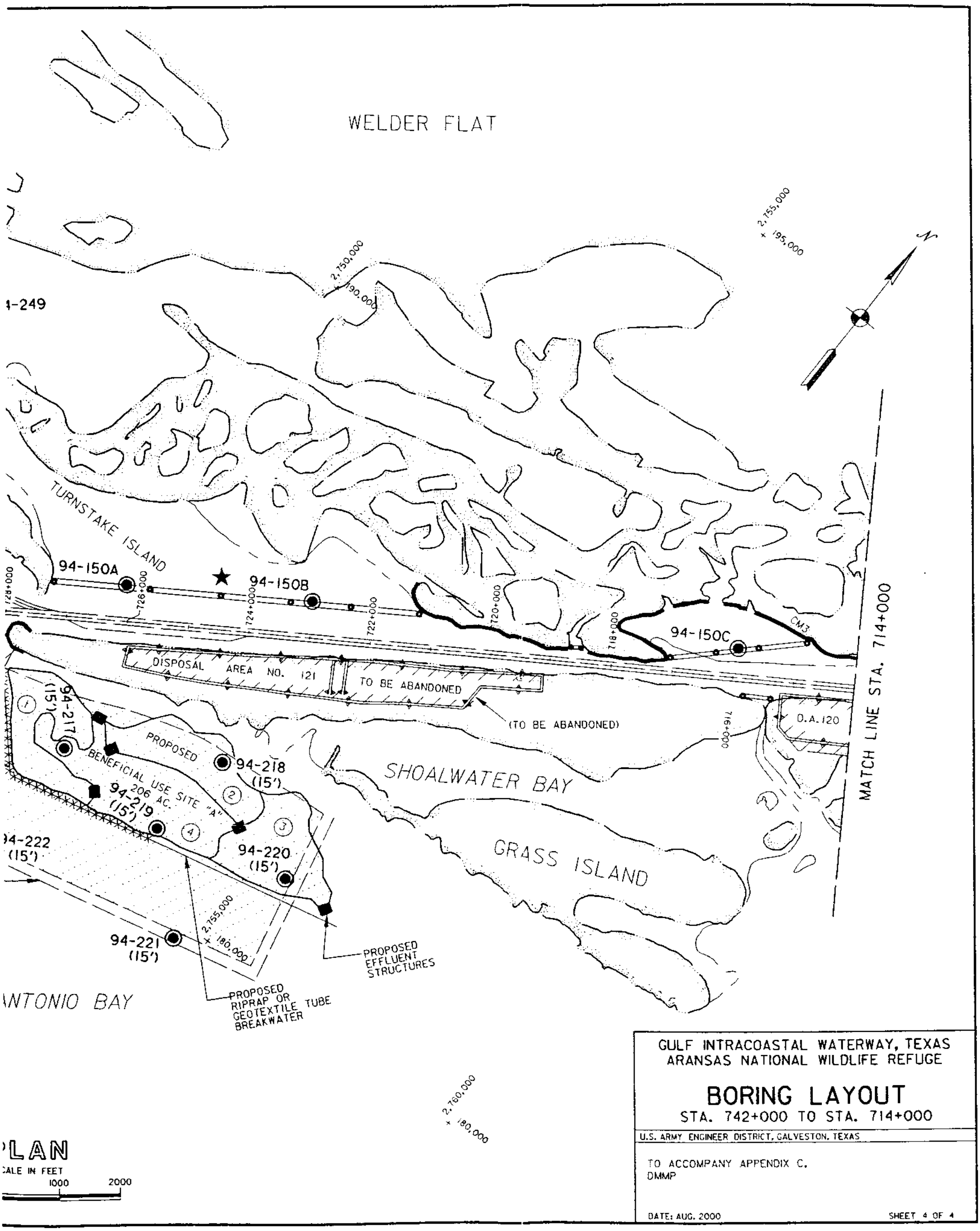
DATE: AUG. 2000

SHEET 3 OF 4

EXHIBIT C-1 SHT. 3



SAN ANTONIO BAY
CHANNEL TO VICTORIA
94-249
94-250
TUR
185,000
2,745,000
2,740,000
180,000
DISPOSAL AREA NO. 122
250'
200'
MATCH LINE STA. 742+000
740+000
738+000
736+000
734+000
732+000
730+000
728+000
ARTICULATED CONCRETE MATTRESS
94-216 (15')
PROPOSED RIPRAP BREAKWATER
2,750,000
180,000
PROPOSED FEASIBILITY MARSH
94-222 (15')
PROPOSED FEASIBILITY BREAKWATER
2,745,000
175,000
LEGEND:
EXISTING LEVEE
EXISTING CONCRETE MATTRESS
PROPOSED CONTAINMENT BOOMS
PROPOSED BREAKWATER
EXISTING MARSH (O&M DEMONSTRATION)
PROPOSED NEW MARSH FROM FEASIBILITY REPORT 1994
CORE BORING LOCATION
EXISTING STAFF TIDE GAGE
BEACON LOCATION
EFFLUENT OUTLET
SAN ANTONIC
PLAN
SCALE IN FEET
1000
0
1000



GULF INTRACOASTAL WATERWAY, TEXAS
ARANSAS NATIONAL WILDLIFE REFUGE

BORING LAYOUT

STA. 742+000 TO STA. 714+000

U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS

TO ACCOMPANY APPENDIX C.
DMMP

DATE: AUG. 2000

SHEET 4 OF 4

EXHIBIT C-1 SHT. 4